HONI SOIT QUI MAL Y PENSE

CRAIGM

PLATE I. (FRONTISPIECE).

MEMOIRS OF THE GEOLOGICAL SURVEY, SCOTLAND.

THE GEOLOGY

OF THE

NEIGHBOURHOOD OF EDINBURGH.

(SHEET 32, WITH PART OF 31.)

SECOND EDITION.

By

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AND

PETROLOGICAL CHAPTERS

BY

J. S. FLETT, M.A., D.Sc.

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PREFACE.

THE present volume forms the second edition of the Memoir on "The Geology of the Neighbourhood of Edinburgh," which was written by H. H. Howell and (Sir) A. Geikie, and published in 1861, when Sir R. I. Murchison was Director General and (Sir) A. C. Ramsay, Local Director. That Memoir described the geology of the districts included in the one-inch map 32—the first published sheet of the Geological Survey in Scotland—together with a strip of ground, about two miles broad, along the eastern margin of Sheet 31. The present edition deals with the same districts, except a small part of the county of Fife to the east of Inverkeithing, which was described by Sir A. Geikie in the Memoir on "The Geology of Central and Western Fife and Kinross" (1900).

The development of the oil-shale fields in the Lothians, after the ground had been originally mapped by the Geological Survey, necessitated the revision of the shale-bearing areas, which was carried out by Mr. H. M. Cadell between 1884 and 1887. This additional information was embodied in a second edition of Sheet 32, published in 1892.

The results of the revision of the Carboniferous districts, which was begun in 1902 and continued at intervals till 1906, by Messrs. Peach, Clough, Hinxman, Grant Wilson, Gibson, Crampton, Maufe, Bailey, Anderson, and Grabham, are incorporated in this volume. These officers have furnished descriptions of their respective areas. Dr. Peach re-examined a tract embracing the city of Edinburgh and Leith, southwards to Liberton and Colinton, thence along the north-west slope of the Pentland chain to the Cairn Hills. Mr. Clough revised the Coal Measures of the Mid-Lothian basin south of Smeaton and Sheriffhall, together with an area between Crossgatehall and Gorebridge, composed partly of Millstone Grit and partly of the Carboniferous Limestone Series. The eastern part of this basin, from Prestongrange to Crossgatehall was re-examined by Mr. Anderson, and from Cousland to Temple by Dr. Crampton; the southern part from Borthwick by Mount Lothian to Carlops and Penicuik, by Mr. Hinxman; the western portion from Penicuik to Gilmerton, by the late Mr. Grant Wilson; and the north-western area from Gilmerton to Portobello and Musselburgh, by Messrs. Gibson and Bailey.

West of Edinburgh and the Pentland Hills, the Carboniferous districts were thus apportioned: to Dr. Crampton was assigned a triangular area stretching from Newhaven and Cramond in the north to the village of Currie in the south; to Mr. Grant Wilson, the fertile tract comprising the oil-shale fields extending westwards to Blackness, Dechmont, and Leven; to Mr. Bailey, the ground surrounding Blackburn and Bathgate; to Mr. Maufe, the central portion of the volcanic area of the Bathgate Hills; to Mr. Grabham the part between Carribber and Linlithgow; and to Mr. Clough the

region between Linlithgow and the Forth. North of the Firth of Forth, Mr. Maufe revised that part of the county of Fife lying between Crombie Point and Inverkeithing.

In 1906 an economic Memoir dealing exclusively with the Oil-shales of the Lothians was published by the Geological Survey, in which the geology of the various shale-fields was described in detail. Only a few typical sections illustrating the structure of the shale region are here reproduced from that Memoir.

The descriptions of the Carboniferous districts have been almost wholly rewritten owing to the acquisition of fuller information, but in some cases the accounts by H. H. Howell and Sir A. Geikie have been retained.

The Lower Old Red Sandstone volcanic rocks of the Braid Hills were revised by Dr. Peach, and of the Pentland Hills by Mr. Cunningham Craig when attached to the staff of the Geological Survey, and afterwards in part by Dr. Peach, but the account of the stratigraphy of that formation has been furnished by Dr. Peach.

The description of the isolated areas of Silurian rocks in Sheet 32 by Dr. Peach and Dr. Horne has been reproduced from the Memoir on "The Silurian Rocks of Scotland," published in 1899.

No systematic re-examination of the glacial deposits was carried out during the revision of the Carboniferous districts, but a brief outline is given of the history of that period based partly on the work of the Geological Survey and partly on the researches of other observers.

Dr. Flett has contributed the chapters on the Petrography of the Volcanic Rocks of the Pentland Hills and of the Carboniferous Volcanic Rocks of the Edinburgh and Linlithgow district. The rock analyses have been made by Dr. Pollard and Mr. Radley.

The lists of fossils in the palæontological part of the Appendix have been compiled by Mr. D. Tait. These lists are based on determinations made by R. Etheridge, junr., Dr. Peach, Dr. Crampton, and Dr. Lee, with the assistance of Messrs. H. B. Brady, T. Rupert Jones, J. W. Kirkby, Dr. Traquair, Dr. Kidston, Dr. Wheelton Hind, and Dr. Foord. Dr. Lee has furnished notes on the Distribution of Life in the Lower Carboniferous Rocks of Sheet 32.

The bibliographical part of the Appendix, containing a list of works referring to the geology of the districts included in this memoir, was prepared by Mr. D. Tait.

Special thanks are due to those associated with the mining industry of Mid and West Lothian for information supplied when the revision was in progress, and to Mr. Reid of Messrs. Leslie and Reid, C.E., for notes regarding the water supply of Edinburgh and the surrounding district.

The photographs reproduced in Plates I. to IV., VI. and VIII., were taken by Mr. R. Lunn, and the micro-photographs in Plates IX. to XII. by Mr. T. C. Hall. The photograph of the east and west dyke in Inchcolm (Plate V.) has been kindly supplied by Mr. A. G. Stenhouse.

The Memoir has been edited by Dr. Horne.

J. J. H. TEALL,
Director.

GEOLOGICAL SURVEY OFFICE,
28 JERMYN STREET, LONDON.
17th November 1910.

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MAP (*at end of Volume*).

Geological Map of Arthur's Seat and the Calton Hill on the scale of six inches to one mile.

EXPLANATION OF SCOTTISH MINING TERMS.

Blaes, argillaceous shale; *Daugh*, coaly fireclay; *Fakes*, shaly sandstone or sandy shale; *Kingle* (sometimes called *Kennel*), very hard or indurated sandstone; *Sclit* or *Sclutt*, coaly blaes or slaty coal.

GEOLOGY OF THE NEIGHBOURHOOD OF EDINBURGH.

CHAPTER I.

INTRODUCTION.

Area, Physical Features, and General Distribution of the Rocks.

The district described in this memoir includes the area within the limits of Sheet 32 of the one-inch map of Scotland, and, for the sake of completeness, a narrow strip about two miles in width along the eastern margin of the adjoining map 31. It thus comprises the greater parts of the counties of Edinburgh and Linlithgow, with portions of Haddington, Peebles, Lanark and Fife. Most of the district described lies to the south of the Firth of Forth and contains the valuable coal-field of Mid-Lothian and almost the whole of the oil-shale fields of the Lothians. Hence it embraces one of those rich mineral tracts in the Midland Valley of Scotland which have contributed so much to the development of the country.

The physical features of the district present that union of level cultivated plains with undulating and hilly ground, varied by the frequent occurrence of abrupt solitary crags, which forms the characteristic scenery of central Scotland. It is divided into two well-marked portions by the chain of the Pentland Hills, which traverses its centre from south-west to north-east and rises to a height of 1898 ft. above the sea. The eastern area consists of a broad plain, which, from the foot of the hills, stretches eastwards into Haddingtonshire and southward until it abuts against the slopes of the Moorfoots. With the exception of the minor undulations incident to a drift-covered district, the continuity of this plain is unbroken except by the long ridge * of the Roman Camp Hill east of Dalkeith, which, beginning near the sea at Prestonpans and running south-west parallel to the Pentlands, divides the plain into two, the western portion being known as the Mid-Lothian Coal-Field, while that to the east includes the coal-basin of East Lothian situated in Sheet 33. The margin of the Firth of Forth truncates both coal-

* The south-west part of this ridge is generally termed the Roman Camp Hill, but this name does not appear in the new edition of Sheet 32. The site of the supposed Roman Camp is indicated by the word Fort in this edition.

fields, the coal seams passing under the sea and reappearing on the opposite shores of Fife.

The great central ridge of the district may be regarded as commencing at the Braid Hills, whence it stretches south-west through the Pentland Hills till it merges into the uplands of Peebles and Lanark. The district to the west of this chain of hills comprises nearly two-thirds of Sheet 32, and presents a physical contour considerably different from that on the east side. With the exception of the broad plain which extends for seven miles to the west of Edinburgh, this western division contains few level spaces of any extent. Throughout the greater part the surface undulates in ridges, of which the general direction may be taken as east and west, but their continuity seldom remains persistent, more frequently they coalesce or branch out into a new series, the determining cause being in many cases some prominent crag or hill of igneous material.

A conspicuous feature along the western margin of the district (Sheet 31) is the ridge of hilly ground running in a north and south direction from Bathgate towards Linlithgow, which, as will presently be shown, is due to the geological structure of the region.

The part of the county of Fife included in Sheet 32 displays physical features characteristic of a Carboniferous district with intrusive igneous rocks, partly covered with superficial deposits.

Before describing the geology of the area in detail, it will be well to give a brief outline of the general distribution of the rocks, the more especially as such an outline will illustrate how closely connected are the geology and the physical geography of a country. The Pentland Hills, forming the backbone of the region, consist fundamentally of highly inclined Upper Silurian shales and grits, covered unconformably by coarse conglomerates and sandstones, and volcanic rocks belonging to the Lower Old Red Sandstone formation. At the north-east end of the chain, and in various places along its north-west side, sandstones and cornstones belonging to the Upper Old Red Sandstone rest unconformably on the older rocks and pass upwards into the basal beds of the Carboniferous system.

The rocks entering into the structure of the Pentland Hills form an anticlinal axis over which the Carboniferous rocks are folded, though, owing to large parallel faults, the regularity of this anticline has been materially disturbed.

Along their south-east margin the Pentland Hills are bounded by a great fault, and the broad plain farther south-east consists entirely of Carboniferous rocks. They form a synclinal trough, the west side of which flanks the Pentland Hills, while the eastern swells up into the Roman Camp ridge. That ridge is an anticlinal axis formed by the lowest group of the Carboniferous Limestone series, which, rising from beneath the Mid-Lothian Coal-field, sinks eastwards below the coal-basin of East Lothian, the latter being included chiefly in Sheet 33.

The district between the north end of the Braid Hills and the sea consists of Upper Old Red Sandstone and Calciferous Sandstone strata, the latter associated with numerous interbedded and intrusive igneous rocks, which give rise to prominent features in Arthur's Seat, Calton Hill and the Castle Rock.

West of the Pentland Hills the Calciferous Sandstone strata, com-

prising the productive oil-shale measures, extend in a great series of anticlines and synclines varied everywhere by detached masses of igneous rock, chiefly of an intrusive character. In spite of frequent repetitions the general dip is westerly, and near the western margin of one-inch Sheet 32 the Carboniferous Limestone series again appears with a middle coal-bearing group, which composes the important Bo'ness and Bathgate coal-fields. In this western area all three subdivisions of the Carboniferous Limestone series are associated with sheets of interbedded and intrusive dolerite and volcanic ash which are absent from this series farther east in the Mid-Lothian coal-basin. The more prominent hills over this western area consist almost uniformly of igneous rock, and the narrow valleys which divide them frequently owe their origin to the denudation of intercalated shales and sandstones, or to lines of fault along which the denuding agents have acted.*

Formations and Rock Groups.

The geological formations occurring within the area are represented in stratigraphical order in the following table with the symbols used in the map:—

	Pleistocene and Recent.	Blown Sand	
		Peat in hollows occupying the sites of old lakes and on hill slopes	
		River Terraces and fresh-water alluvia	
		Raised Beaches and marine alluvia	
		Glacial or Fluvio-glacial sands, gravels and brick clays	
		Boulder Clay	
Carboniferous.	Upper.	Middle Coal Measures? Red Sandstone Group	d^6
		Lower Coal Measures	d^5
		Upper Roslin Sandstone Series or Millstone Grit	d^4
	Lower.	Lower Roslin Sandstone Series or Millstone Grit	d^4
		Carboniferous Limestone Series	d^2
		Calciferous Sandstone Series	d^1
Old Red Sandstone.	Upper.	Red sandstones and cornstones	c^3
	Lower.	Red sandstones and conglomerates	c^1
Silurian.	Upper.	Downtonian	b^7
		Wenlock and Ludlow	b^6
	Lower.	Llandeilo-Caradoc	$b^{2,3}$

IGNEOUS ROCKS.

A. *Contemporaneous with the formations among which they lie.*

In Carboniferous Limestone Series.	Lava flows of Basalt or Dolerite of the Gallaston and Dalmeny types	vBd^2
	Basaltic Tuff	BZd^2
In Calciferous Sandstone Series.	Lava flows of Basalt of Gallaston and Dalmeny types	vBd^1
	" " " Craiglockhart type	xBd^1
	" " " Dunsapie type	yBd^1
	" " Mugearite	oWd^1
	Basaltic Tuff	BZd^1

* The foregoing description with some alterations has been taken from the first chapter of the "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861, written by Sir A. Geikie.

In Lower Old Red Sandstone.	Lava flows of Basalt	Bc^1
	„ „ Augite and Hypersthene Andesite	pAc^1
	„ „ Hornblende and Mica Andesite	hAc^1
	„ „ Trachyte	Tc^1
	„ „ Rhyolite	Rc^1
	Andesitic Tuff	AZc^1
	Rhyolitic Tuff	RZc^1

B. *Intrusive in the formations among which they lie.*

	Dolerite of uncertain character and age	D
Permo-Carboniferous.	Quartz Dolerites in sheets, and dykes with east and west trend	qD
Lower Carboniferous.	Picrite	U
	Olivine Dolerite and Teschenite	tD
	Basalt and Dolerite of Hillhouse type	uD
	„ „ Dalmeny type	vD
	„ „ Craiglockhart type	xD
	„ „ Lion's Haunch or Dunsapie type	yD
	Basaltic Tuffs in Necks	BV
	Agglomerate „ „	V
Pre-Carboniferous.	Necks of Lower Old Red Sandstone age	Vc^1
	Lamprophyre	L
	Diorite	H
	Felsite and Microgranite	F

General Sketch of the Geology of the District.

The oldest rocks represented in this region belong to the Silurian system, and range from Llandeilo to Downtonian time. They form the floor on which the younger Palæozoic strata repose with a marked unconformability, and appear chiefly as inliers in the Pentland Hills, where the basal conglomerates of the Lower Old Red Sandstone are composed mainly of greywacke pebbles derived from the old Silurian tableland.

The dominant types of strata in the Pentland Hills that belong to the Wenlock and Ludlow divisions of the system, consist of pebbly grits, greywackes, concretionary sandstones, shales and mudstones which yield a prolific fauna of brachiopods, lamellibranchs and gasteropods. A marked change in the phase of sedimentation is presented by the Downtonian rocks which comprise red and chocolate-coloured sandstones of Lower Old Red Sandstone type, with red and green mudstones yielding remains of the Downtonian fish fauna of Lanarkshire. The researches of Messrs. Henderson and Brown proved that these red sandstones, which were at first regarded by the Geological Survey as a conformable portion of the Lower Old Red Sandstone, are an integral part of the Silurian succession—a conclusion which was confirmed in the course of the re-examination of the ground in 1896.

Towards the close of Downtonian time the Silurian strata were subjected to great lateral compression and were thrown into a series of folds, the axes of which run in a north-east and south-west direction parallel to the major axis of the Silurian tableland. It is interesting to observe that some of the graptolite-bearing bands of Wenlock age, which occur near the North Esk Reservoir, have been found at Habbie's Howe in the heart of the Pentland Hills, and at Hare Hill on the north slope of that chain, thus showing that the Wenlock,

Ludlow and Downtonian rocks must together have been folded and extensively denuded before the outburst of volcanic activity in Lower Old Red Sandstone time.

The rocks belonging to the lower division of the Old Red Sandstone, as already indicated, are prominently developed in the Pentland Hills. The basal members consist of conglomerates and sandstones which rest on the various zones of the Upper Silurian formation from the Downtonian group to the Wenlock shales and grits. But the characteristic feature is the great succession of volcanic rocks, ranging from basalts and basic andesites through acid andesites and trachytes to rhyolites, which have become familiar to geologists through the descriptions of Charles Maclaren and Sir A. Geikie. The acid ejections, however, do not form the highest members of the sequence but are intercalated with basalts and basic andesites. Of special interest is the result of the petrographical examination of the decomposed claystones of the Braid Hills by Dr. Flett, who regards them as trachytes (Chap. IV.). The lavas and tuffs are accompanied by intrusive igneous materials, comprising diorite, microgranite and felsite, while in the northern part of the chain remnants of small volcanic orifices are to be found.

Towards the close of Lower Old Red Sandstone time crustal movements again supervened, whereby the volcanic rocks were folded along an axial line trending north-east and south-west, and were subjected to prolonged denudation. It is highly probable that some of the faults now traversing these rocks may have been developed during these movements. During this interval of time, represented elsewhere by the Middle Old Red Sandstone, the volcanic series was locally removed and the underlying Silurian rocks were laid bare. Hence we find the basal beds of the Upper Old Red Sandstone overstepping each member of the lower division together with its igneous intrusions until they rest on the Upper Silurian strata.

The type of sedimentation characteristic of the Upper Old Red Sandstone in other parts of Scotland is to be found in the neighbourhood of Edinburgh and on the flanks of the Pentland Hills, where the strata consist of reddish grey grits, sandstones, marls and cornstones. The discovery of fish remains, determined by Dr. Traquair to be fragments of *Holoptychius nobilissimus*, in the sandstones of Craigmillar and beneath Salisbury Craigs, furnished conclusive evidence of the age of these sandstones, which in the previous editions of Sheet 32 were grouped with the Carboniferous formation. This discovery is a striking confirmation of the conclusions of Mr. J. G. Goodchild,* who previously suggested this correlation on the ground of the lithological characters of the strata, and especially of the cornstone associated with the sandstone of Salisbury Craigs.

The Upper Old Red Sandstone passes conformably upwards into the Carboniferous formation, though there is a marked palæontological break between the two as proved by the researches of Dr. Traquair.†

The Calciferous Sandstone series comprises two subdivisions, the lower one being termed the Cementstone group. As developed in the Edinburgh district it consists of grey, green and red mudstones,

* *Trans. Edin. Geol. Soc.*, 1898, vol. viii. pp. 2–9.

† "List of the Fossil Dipnoi and Ganoids of Fife and the Lothians," *Proc. Roy. Soc. Edin.*, 1890, vol. xvii. p. 385.

and shales with cementstone bands, occasional sandstones, and rarely some thin seams of dark carbonaceous shale yielding plants, ostracods, and Palæoniscid fish scales of undoubted Carboniferous type. This phase of sedimentation is characteristic of the Ballagan group of the west of Scotland. A marked feature of this period is the outbreak of volcanic activity in the Edinburgh district, the relics of which are typically developed in Arthur's Seat and the Calton Hill, where there is a succession of lavas ranging from olivine basalts to mugearites. The re-examination of Arthur's Seat by the Geological Survey confirmed the later view of Charles Maclaren and the conclusions of Professor Judd regarding its structure, namely, that the lavas and ashes, together with the central agglomerates and their associated igneous rocks, belong to one period of volcanic activity. Two separate vents have been recognised on the crest of Arthur's Seat, the larger one showing a slight displacement of the focus of eruption during the history of the volcano.

The volcanic horizon of Arthur's Seat and the Calton Hill has been detected on Corston Hill, north-west of the Pentland Hills, where the lavas may have been ejected from an independent centre.

The upper division of the Calciferous Sandstone series comprises a succession of strata of great economic importance, and is known as the Oil-shale group. It contains, in its higher part, beds of coal, usually of inferior quality, and farther down, several valuable seams of oil-shale, interstratified with beds of sandstone, shale, fireclay, marl and estuarine limestones, and underlain by the Wardie Shales and Granton Sandstones. In the last two subdivisions, thin seams of oil-shale have been detected, which yield a small quantity of crude oil and sulphate of ammonia.

The Carboniferous Limestone series is roughly divisible into the three following groups:—

3. Upper Limestone group, including three or four thin marine limestones.
2. Edge Coal group or Bo'ness and Bathgate Coal group.
1. Lower Limestone group, including various marine limestones, some of which attain a considerable thickness.

These three subdivisions are represented by the same colour on the published map. The basal bed of the Upper Limestone group is the Index or No. 4 Limestone, and the top of the Lower Limestone group is marked by the first band of limestone beneath the series of Edge Coals.

Group 2 is of great economic importance, and yields a more valuable series of coals than the Coal Measures proper, so far as this part of Scotland is concerned. It is often termed the Lower Coal Measures by those connected with the Mining Industry.

The limits of the Roslin Sandstone series or Millstone Grit nearly coincide with those laid down during the original survey of the district, but, as the base line is now everywhere drawn at the top of the Castlecary (No. 6) Limestone, additional strata are occasionally included. In accordance with the determinations of the plant and fish remains by Dr. Kidston and Dr. Traquair respectively * this group falls palæontologically in two divisions, one being classed with the

* "Summary of Progress," *Mem. Geol. Sur.* for 1903, p. 118.

Upper and the other with the Lower Carboniferous rocks. Although the Millstone Grit is shown by one colour in Sheet 32, a boundary between these two subdivisions has been drawn where the evidence is regarded as conclusive.

Next in order come the Lower Coal Measures, with numerous valuable seams of coal, succeeded by red sandstones and marls, which, with some hesitation, have been classed with the Middle Coal Measures. The latter have a striking resemblance to the Upper Barren Measures of Lanarkshire and Fife. The Fifeshire beds have been classed by Dr. Kidston with the Middle Coal Measures of England,* but no sufficient evidence has yet been obtained to prove the age of this subdivision in Mid-Lothian, the few fish and plant remains which have been found being common to the Middle and Lower Coal Measures.

One of the striking features of the Carboniferous area described in this memoir is the great development of intrusive igneous rocks, which are now grouped in two divisions according to their age and are expressed by different tints in the new edition of Sheet 32. The older set, consisting of teschenite and olivine dolerite intrusions allied petrologically to the Carboniferous lavas, have been referred to the same general period as the extrusion of the lavas.† No contemporaneous volcanic rocks are known to occur in this area above the Carboniferous Limestone series, and these intrusions are in all probability older than the Millstone Grit. The later set, composed of quartz dolerites, which occur in the form of sills and east and west dykes, are allied in petrological character to the Whin Sill of the North of England.‡ They have been proved to be subsequent to the Lower Coal Measures (d^5) and are probably of late Carboniferous or Permo-Carboniferous age.

After the close of the Carboniferous period crustal movements again ensued, whereby the Carboniferous strata and the associated igneous rocks were thrown into a series of anticlines and synclines, the axes of which trend generally in a north-east and south-west direction. It is worthy of note that the chain of the Pentland Hills roughly coincides with one of these anticlinal folds whose eastern limb is intersected by the great Pentland fault. This dislocation may be said to form the septum between the arch of the Pentland Hills and the Mid-Lothian coal-basin to the east. It is highly probable that it follows the line of one of the strike faults established in the Lower Old Red Sandstone rocks during their first plication, but the movement during post-Carboniferous time was evidently extremely powerful. The high inclination of the Carboniferous strata along the west side of the Mid-Lothian basin extends eastwards for over a mile from the Pentland fault. The structure is further complicated by the occurrence of minor troughs in some of which the western limb is inverted, as for example at the western edge of the Gilmerton basin, in the Nine Mile Burn

* "The Geology of Central and Western Fife and Kinross," *Mem. Geol. Sur.*, p. 146; and R. Kidston, "On the Various Divisions of British Carboniferous Rocks, as determined by their Fossil Flora," *Proc. Roy. Phys. Soc. Edin.*, 1893, vol. xii. p. 203.

† Sir A. Geikie, Presidential Address, *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. p. 141.

‡ Dr. Teall, "British Petrography," p. 187.

and in the Amazondean Burn, a tributary of the Esk (p. 184). The area affected by these complex structures is too extensive to be due to subsidence along a normal fault. They seem to indicate that the Pentland fault is a reversed one produced by an overthrust from the north-west.

The Oil-shale group, covering a belt several miles in width in the western part of Sheet 32, has been thrown into a succession of abrupt domes and basins whose longer axes trend in a N.N.E. and S.S.W. direction. The steeper sides of these synclines form the western limbs, thus indicating that, as in Mid-Lothian, the thrust was from the north-west.

Between the folding and denudation of the Carboniferous strata and the Glacial period there is a long cycle of time unrepresented so far as this region is concerned. It is evident, however, that the main topographical features had been determined before the advent of the ice-age. The drainage system of the Pentland Hills and the transverse passes across the chain throw some light on the earlier stages in the evolution of the topography of the district. It is observable that most of the streams rise near the north-west side of the chain and flow southwards or eastwards. Some, indeed, rise on the less elevated ground north-west of the hills and cross the range in comparatively matured valleys. Only a few flow to the north and west. This distribution seems to indicate the existence of an older drainage system, when the streams crossed the tableland from the north-west before the development of the midland plain. The transverse passes may thus have been produced by streams of greater volume than those now draining them, which have been beheaded in the course of the evolution of the Midland Valley on the north-west side of the Pentland Hills. On the south-east side of the chain the Esk has captured the streams towards the north, and the river Medwyn the streams towards the south-west, while the Lyne alone preserves its old south-east course across the intervening hollow, and enters the Southern Uplands as a tributary of the Tweed.

Description of Horizontal Section.

The horizontal section on the scale of one inch to a mile in the new edition of Sheet 32 shows the general arrangement of the strata along a line extending from the south side of the Roman Camp Hill, north-westwards by Straiton and the Pentland Hills to the neighbourhood of Bo'ness. An obscure area, about five miles in length, that intervenes between the Water of Leith and the river Almond has been omitted.

The marked unconformability between the folded Silurian strata and the gently inclined Lower Old Red Sandstone rocks of the Pentland Hills is clearly illustrated, together with the volcanic sequence dipping in a south-easterly direction. The complete discordance between the Lower Old Red rocks and the Upper Old Red Sandstone is shown near Kinleith, where a thin development of the latter with the overlying cementstones rests transgressively on an eroded platform of the lower members of the volcanic series. On the north-west side of the chain the strata overlying the

volcanic horizon of Arthur's Seat are let down by means of a normal fault, and on its south-east margin the Oil-shale group is brought into contact with the highest members of the Lower Old Red volcanic series along the Pentland fault.

The section further illustrates the sharp plication of the Oil-shale group close to the Pentland fault and the high inclination of the Carboniferous Limestone series for some distance to the east. In the centre of the Mid-Lothian basin the strata are represented as almost horizontal, beyond which the members of the Lower Limestone group rise to the surface in Roman Camp Hill.

The western portion of the section from the river Almond to a point beyond Three Miletown depicts the various undulations of the Oil-shale group whereby the workable shales are made to cover a broad belt of country. Westwards they pass beneath the Lower Limestones and the overlying volcanic series associated with the Bo'ness coals. B. N. P., C. T. C., J. H.

CHAPTER II.

THE SILURIAN ROCKS.

Llandeilo-Caradoc.

The strata belonging to the lower division of the Silurian system are of small extent and form part of the northern edge of the Silurian tableland of the Southern Uplands. One portion occurs in the south-east corner of the map, south of Middleton Moor, the other lies about two miles south-east of Penicuik, where it forms a promontory running into the Mid-Lothian basin. In both areas the rocks consist of green greywackes, pebbly grits and shales, striking E.N.E. and W.S.W. at high angles, in accordance with the general trend of the Silurian strata in the ground to the south. Hitherto these sediments have proved unfossiliferous, but, in the adjoining tracts immediately to the south and south-west, the Arenig radiolarian cherts and the Glenkiln Shales with some of their characteristic graptolites (Upper Llandeilo) appear along isoclinal folds among barren greywackes, grits and shales of younger age.* In certain localities near the northern margin of the tableland, the Glenkiln Shales undergo modification and occur as thin films among greywackes, thus showing that the Moffat type of sedimentation in Upper Llandeilo time is giving place, in the north, to coarser sediments. It is worthy of note also that near Leadburn, about a mile beyond the south margin of Sheet 32 and about three and a half miles S.S.E. of Penicuik, there is an excellent exposure of the "Haggis Rock"—a fine conglomerate containing fragments of the radiolarian chert and Arenig volcanic rocks, which is regarded as of Caradoc age. On these grounds the strata south of Middleton Moor, and at Gray Brae south-east of Penicuik, may be referred to Llandeilo-Caradoc time.

Wenlock, Ludlow and Downtonian.

Within the range of the Pentland Hills and completely surrounded by various subdivisions of the Old Red Sandstone and the associated igneous rocks, three isolated patches of Upper Silurian strata have furnished a definite assemblage of organic remains. These areas may be grouped as follows: (1) the tract on the south side of the watershed extending from the Lyne Water by the North Esk River to the Green Law, a distance of three and a half miles; (2) the narrow belt running along the east slope of the Black Hill from Habbie's Howe at Loganlee to near Craigenterrie; (3) the Hare Hill and Bavelaw Castle inlier.

* "Silurian Rocks of Scotland," *Mem. Geol. Sur.*, 1899, pp. 250-253.

i. INLIER EXTENDING FROM THE LYNE WATER BY THE NORTH ESK TO THE GREEN LAW.

In the Geological Survey memoir on "The Silurian Rocks of Scotland," p. 17, an account is given of the gradual development of our knowledge regarding the geological structure and palæontological subdivisions of the Silurian rocks of the Pentland Hills. It was indicated that the general order of succession in the North Esk as given by Sir A. Geikie in the memoir on "The Geology of the Neighbourhood of Edinburgh" has been confirmed by subsequent investigators. He showed that by following the Esk from Carlops northwards to the watershed, the observer crosses the series nearly at right angles to its strike, and that with the exception of certain minor folds an ascending succession is traceable from the green, grey and reddish shales at the reservoir to the Downtonian or passage beds near the watershed. The researches of various local observers, notably of Messrs. John Henderson and D. J. Brown, have proved the existence of certain palæontological zones, some of which yield a large assemblage of organic remains. Messrs. Henderson and Brown further showed that the Downtonian or passage beds at the head of the North Esk section are traceable across the hills in a south-west direction to the Lyne Water, suggesting at the same time, from the presence of marine fossils in the conformable Red Sandstone series, that the latter might belong to the Silurian instead of the Lower Old Red Sandstone system.*

At the southern limit of the section, below the reservoir, the river and the adjoining rivulets have laid bare numerous exposures of green, grey and reddish shales with occasional bands of grit, which dip sometimes towards the south-east at angles varying from 50° to 70°. From certain seams below the reservoir the Geological Survey obtained specimens of *Monograptus*, *Nucleospira pisum* (J. de C. Sow.), *Cucullela* sp., while Messrs. Henderson and Brown have recorded the following forms: *Monograptus priodon* (Bronn), *Retiolites geinitzianus* (Barr.), *Glassia compressa* (J. de C. Sow.), and *Theca* sp. from a knob near the cottage at the reservoir.

Northwards towards the northern side of the reservoir, strata of the same general type as those just described are well seen on the shore of the lake above the mouth of Gutterford Burn. Here occur zones of green and red lumpy shales, with occasional grit bands, containing abundant remains of *Dictyocaris ramsayi* Salt., which are either vertical or inclined to the north-west at high angles. On the right bank of the river, near the head of the reservoir, certain flaggy bands of sandy grit, east of an old quarry, yielded to the Geological Survey crinoid stems, *Dictyocaris ramsayi*, *Orthonota* and *Pterinea*; and to Messrs. Henderson and Brown, *Glassia compressa* and *Bellerophon dilatatus* J. de C. Sow.

The Gutterford Burn—an important tributary of the North Esk from the north-east—displays an admirable section of this series of shales, which has become widely known within recent years from the discovery by Mr. Henderson of certain seams, yielding new forms of Eurypterids, described by Dr. Malcolm Laurie. These organic

* *Trans. Edin. Geol. Soc.*, vol. i. p. 272.

remains are associated with a few species of graptolites of characteristic Wenlock types. Of further interest is the occurrence of a thin band of coralline and encrinital limestone and certain beds containing well-preserved remains of star-fishes.

The strata in the Gutterford Burn consist generally of green and grey shales with bands of micaceous flaggy greywacke and red and purple shale, which, from the constant change of dip, are apparently repeated by sharp folds. Indeed, throughout some parts of the section the dip is so persistently to the south-east that many of the outcrops may be inverted. Near the head of the stream, which is about a mile in length, green and buff-coloured mudstones alternate with green micaceous sandy flags and greywackes. At a point about twenty-five yards north from the ruin of Gutterford shepherd's house, on the east bank, the fossiliferous beds yield well-preserved specimens of star-fishes. From the green and buff-coloured mudstones and shales the following specimens have been obtained:—

Monograptus vomerinus *Nich.*
Palæaster sp.
Cheirurus bimucronatus (*Murch*).
Phacops stokesi *M. Edw.*
Glassia obovata (*J. de C. Sow*).
Orthis sp.

The star-fishes, however, occur in greater abundance in one of the green sandy bands, varying in thickness from a few inches to a foot and a half, which are associated with the mudstones. These have yielded specimens of *Ptilodictya*, *Monograptus vomerinus* Nich., *Palæaster*, *Palæasterina*, *Protaster* and *Periechocrinus*.

About a quarter of a mile below the ruin of the shepherd's house the beds crop out which have yielded the new forms of Eurypterids. The locality is about half a mile up from the North Esk Reservoir, where on the east bank the strata consist of flaggy micaceous greywackes, breaking with an irregular fracture and dipping towards the south-east at an angle of 80°. A characteristic feature of this Eurypterid bed is the abundance on the divisional planes of *Dictyocaris ramsayi* Salt. forming large black patches about an inch and a half across. Graptolites, though numbering few species, are not of infrequent occurrence, and, considering the sandy nature of the material, are in fairly good preservation.

The species of arthropoda described from this bed by Dr. Malcolm Laurie * are given in the following list:—

Palæophonus loudonensis *Laurie.*
Slimonia dubia *Laurie.*
Stylonurus macropthalmus *Laurie.*
„ ornatus *Laurie.*
„ elegans *Laurie.*
Drepanopterus lobatus *Laurie.*
„ pentlandicus *Laurie.*
Drepanopterus bembycoides *Laurie.*
Eurypterus scoticus *Laurie.*
„ minor *Laurie.*
„ conicus *Laurie.*
„ cyclophthalmus *Laurie.*
Bembicosoma pomphicus *Laurie.*
Ceratiocaris sp.

About fifteen yards down stream from the Eurypterid band a seam of limestone about ten inches thick lies embedded in mudstones, shales and greywackes. Weathering with a rich brown colour, this rock in fresh fracture is found to be made up in large part of crinoid stems, while containing also remains of corals, brachiopods and several other calcareous organisms.

Returning to the North Esk section, we find in certain quarries

* *Trans. Roy. Soc. Edin.*, vol. xxxvii. p. 151, and vol. xxxix. p. 575.

near the second rivulet, about a third of a mile above the reservoir, a group of vertical strata, about 200 ft. thick, which differ considerably in character from the great shaly division just described. They consist of hard sandstones and quartzose grits, which contain fossils easily discernible on weathered surfaces, and in the centre of the quarry a shaly band yields specimens of *Orthonota amygdalina* (J. de C. Sow.) (Band B of A. Geikie, C of Henderson and Brown, 5C in Fig. 1). These grits are succeeded by greenish-grey shales and sandy bands, which are highly fossiliferous (Band D of Henderson and Brown, 5D Fig. 1). They are specially rich in brachiopods and lamellibranchs, and yield a considerable number of gasteropods and a few cephalopods and trilobites.* This zone can be traced along the south slope of the tributary valley of Wetherlaw Linn, and still farther to the south-west it reappears near the head of the Deerhope Burn, where it has yielded a large number of characteristic fossils.

In the Esk section, the beds of the succeeding zone (Band E of Henderson and Brown, 5E, Fig. 1) are exposed at the mouth of the Wetherlaw Linn—a small tributary stream on the west side of the valley—and also on the west bank of the Esk, a few yards to the north of that tributary. They consist of mudstones, shales and sandy bands of a greenish-grey tint, and weather with a marked concretionary structure. In certain layers, they are crowded with casts of fossils, two of the characteristic forms being *Plectambonites transversalis* (Wahl.) and *Amphispongia oblonga* Salt. This prolific zone preserves its highly fossiliferous character in the lower portion of the Wetherlaw Linn Burn; it likewise passes south-westwards across the head of Deerhope Burn, and is eventually overlapped by the greywacke-conglomerates and sandstones at the base of the Lower Old Red Sandstone.

Next in order in the Esk section, at a point about 150 yds. north of Wetherlaw Linn, come concretionary greenish-brown sandstone and shales (Band F of Henderson and Brown, 5F in Fig. 1), which furnish numerous and well-preserved specimens of *Orthoceras maclareni* Salt. In addition to this form, the Geological Survey has collected from it *Dictyonema verisimile* (Salt.), *Rhynchonella nucula* (J. de C. Sow.), *Platyceras antiquatum* (Salt.), *Entomis tuberosa* Jones, with a fragment of a crustacean; while Messrs. Henderson and Brown have obtained also *Pholidops implicata* (J. de C. Sow.), *Spirifer* sp., *Pterinea retroflexa* (Wahl.) and *Conularia sowerbyi* Defr.

A little farther north, the Esk is joined from the west by the Henshaw Burn, in which, a few yards from its foot, yellowish-brown, sandy, concretionary and sparingly fossiliferous bands appear. These are rapidly succeeded by dark-brown, sandy shales yielding a large assemblage of organic remains (Band H of Henderson and Brown, 5H, Fig. 1). Among the noteworthy palæontological features of this zone are: (1) the great abundance of a new species of *Rhynchonella* discovered by Mr. Haswell and named by him *R. pentlandica*; and (2) the common occurrence of *Platyschisma simulans* Salt. Indeed, in the North Esk section the members of this zone lie not far beneath the Downtonian or passage beds, for they graduate upwards through some green sandy shales and soft red shales into a band of red

* Lists of fossils collected from Band D are given in "The Silurian Rocks of Scotland," pp. 596, 597.

FIG. 1.—Section across the Upper Silurian Rocks of the Pentland Hills, exposed in the North Esk and its tributaries (Length two miles and a half).

d^1, d^2, Lower Carboniferous. c^3, Upper Old Red Sandstone.

Lower Old Red Sandstone. { Poc^1, Andesites, etc. c^1, Conglomerates, sandstones, etc.

6. Downtonian. { 6e, Chocolate-coloured sandstone. 6d, Red sandstone with large pebbles of quartzite. 6c, Red and green mudstones (Fish-bands). 6b, Red sandstones. 6a, Conglomerate with igneous pebbles.

5. Wenlock and Ludlow. { 5H, *Platyschisma* (*Trochus*) beds. 5G, Dark-brown sandy shales. 5F, Concretionary sandstone and shale, with *Orthoceras maclareni*. 5E, Mudstones, etc., crowded with fossils. 5D, Greenish-grey shale and sandy bands. 5C, Conglomerate, grit and sandstone. 5B, Sandstone and grit. 5A, Greywacke and shale.

conglomerate (6a, Fig. 1), which here marks the base of the conformable red sandstone series. In the first edition of the Geological Survey Map of the Edinburgh region (Sheet 32), these soft red shales and conglomerates were correctly taken as indicating the base of the conformable red sandstone series, but in the sequel it will be shown that Messrs. Henderson and Brown were likewise right in their contention that these red beds and the underlying Ludlow rocks are prolonged south-westwards to the Lyne Water, where they appear to the south of Hareshaw.

The exposures of this overlying Downtonian series both in the North Esk and Henshaw Burn are by no means satisfactory, as the sections are not continuous, but taken in connection with the evidence furnished by the Lyne Water, the strata may be correlated in a general way with their probable equivalents in the Lesmahagow region. In the North Esk they consist of red and yellow sandstones, grits and shales, which are exposed only at intervals in the stream northwards for a distance of about 300 yds. At their northern limit they are abruptly truncated by a fault which brings down against them the Upper Old Red Sandstone (c^3, Fig. 1). In like manner, in the Henshaw Burn, similar red sandstones appear at intervals, and at one point near their northern limit a band of conglomerate with a few quartzite pebbles (6d, Fig. 1), recalls the quartzite conglomerate that overlies the fish-bed in the Lesmahagow region. In these sections we fail to find the green shales associated with the conformable red sandstones at Lesmahagow and in the Lyne Water. There are, however, numerous gaps where no strata are visible, so that these rocks might quite well occur in the North Esk section though not at present exposed there. The discovery by Messrs. Henderson and Brown of *Entomis tuberosa* Jones, *Platyschisma helicites* (J. de C. Sow.), and fragments of an *Orthoceras* in certain yellow and red beds on the Deerhope Rig, at a point about 600 yds. from the foot of the Henshaw Burn, may be of importance, if these fossils really occur within the Red Sandstone series.

The section in the Lyne Water at the south-west limit of the Upper Silurian inlier of the Pentland Hills lays open an important development of Upper Ludlow rocks. A small tributary that joins the Lyne from the east, at a point about 300 yds. south of Hareshaw shepherd's house, flows nearly parallel to the general strike of the Silurian strata, which here consist of green shales and mudstones, resembling the Upper Ludlow rocks of the North Esk. Along their southern limit they are faulted against the greywacke-conglomerate, which forms the base of the sedimentary strata underlying the volcanic division of the Lower Old Red Sandstone. Towards the close of 1896, a careful search for fossils was made in the green shales and mudstones exposed in this burn, with the result that some of the characteristic forms of the Upper Ludlow rocks were obtained in considerable numbers.

In the Lyne Water, at the junction of the two small streams, a small exposure of conglomerate may be seen, whose relations are uncertain, but which is probably faulted against the Silurian rocks, for there is here evidence of much disturbance. Immediately to the north of this conglomerate the green shales and mudstones of Upper Ludlow age reappear.

Northwards, at a prominent bend in the Lyne Water to the west, and about 270 yds. south of Hareshaw shepherd's house, coarse conglomerate is met with, dipping towards the north-west at high angles. It contains large pebbles of porphyry and other rocks, but these are hardly distinctive enough to determine the precise geological horizon of this band. At the point where the Lyne leaves its east and west course and resumes its normal trend, this coarse conglomerate is bounded on the west side by a north and south fault, having a downthrow to the east, which brings it in contact with fine conglomerate and red sandstones, well seen on the west bank of the Lyne about 260 yds. south of Hareshaw. These pebbly and sandy sediments are evidently the basement beds of the conformable red sandstone series (Downtonian). They are exposed at intervals in the bed of the Lyne Water northwards as far as the shepherd's house of Hareshaw, and are either vertical or inclined at high angles to the north-west.

Farther up the same watercourse these conformable red sandstones are succeeded by green and blue shales, and mudstones with bands of flaggy greywacke, which, at a bend in the stream one-third of a mile north of Hareshaw, have yielded fragments of *Dictyocaris*. From their lithological characters they are evidently the counterpart of the green and grey slaty shales, which, in the Lanarkshire area, overlie the first zone of red sandstones and underlie the conglomerate so abundantly charged with quartzite pebbles. During 1898, Mr. Tait detected a brown sandy shale, on both sides of the Lyne Water north of Hareshaw, which yielded the fossils characteristic of the *Glauconome* zone in the Downtonian rocks of Lanarkshire. On the east bank of this stream, 20 yds. north of the sheepfold, about one-third of a mile north of Hareshaw, this band yielded a sponge, *Glauconome*, *Spirorbis*, together with a fragment of one of the Downtonian fishes, *Ateleaspis tessellata* Traq. Moreover, along the line of strike, about three-quarters of a mile north-east of the locality just referred to, the *Glauconome* band was noted in the Lynslie Burn.

Northwards in the Lyne Water, these green mudstones and shales are followed by red pebbly sandstones and shales with sun-cracks, which extend up stream for a distance of a quarter of a mile, and can be followed along the strike to the north-east, for about half a mile to the Lynslie Burn. To the north of this narrow belt of red sandstones, green and red mudstones, and shales again appear which are visible in the Lyne Water and in a tributary from the east, up to its junction with the Lynslie Burn. In the Lyne Water below the fork, these mudstones have yielded detached fragments of fishes, and near the foot of Lynslie Burn, close to the red sandstones, they furnished to Mr. Tait, a sponge (?), crinoid stems, *Spirorbis*, together with minute fragments, chiefly scutes, of the Downtonian fishes *Birkenia elegans* Traq., *Ateleaspis tessellata* Traq., and *Lasanius problematicus* Traq. The stratigraphical horizon of the more northerly belt of red sandstones is not quite clear; it may be a repetition by folding of the sandstone belt south of Hareshaw.

The green mudstones and shales north of the second belt of red sandstones in the Lyne Water, in turn, are followed by red sandstones with red and green shaly partings and thin bands of

conglomerate, which are covered unconformably by the greywacke-conglomerate and sandstones that form the base of the great volcanic series of Lower Old Red Sandstone age. It is of importance to note that, in the Lyne section, the quartzite conglomerate which overlies the fish-band in Lanarkshire has not hitherto been observed.

From the evidence now advanced regarding the main Upper Silurian inlier of the Pentland Hills, the following conclusions may be drawn:—

(1) In the lower portion of the North Esk section, to the south and north of the reservoir, and especially in the Gutterford Burn, an important development of Wenlock rocks can be separated on palæontological grounds from younger strata.

(2) In the higher part of the North Esk, to the north of the Wetherlaw Linn Burn, representatives of Ludlow rocks contain some of the characteristic fossils of the Upper Ludlow rocks of Lanarkshire.

(3) In the Esk section, and again in the Lyne Water, green shales and mudstones (Upper Ludlow) pass upwards into a conformable series of strata (Downtonian), composed of conglomerates with red sandstones, and green and grey shales, and greywackes, the latter yielding some organic remains found in the Wenlock and Ludlow Rocks.

(4) Between the Wenlock, Ludlow and Downtonian strata on the one hand, and the volcanic series of the Lower Old Red Sandstone on the other, there is a complete discordance, as the Old Red conglomerates with greywacke pebbles, derived from the Silurian tableland, rest on the upturned edges alike of Wenlock, Ludlow and Downtonian strata.

ii. THE LOGANLEE AND CRAIGENTERRIE INLIER.

During the re-examination of the Pentland Hills, Mr. E. H. Cunningham Craig obtained evidence to prove that the Silurian strata at Loganlee are continuous with those near Craigenterrie. This narrow belt is truncated on the east side by a fault that brings down the contemporaneous igneous rocks of Lower Old Red Sandstone age, while on the west side it is bounded by the mass of intrusive microgranite of the Black Hill belonging to the same period of volcanic activity.

Westwards from the Loganlee Reservoir, the Silurian strata are exposed by the roadside, at a point about 250 yds. from the lake, and they likewise appear for a distance of 200 yds. up the valley. Towards the north-east they are visible on the hill-slope, and likewise in a streamlet that empties into the reservoir. There is little variety in the character of the strata, as they consist mainly of grey slaty shales. Mr. Henderson found in them several species of graptolites, regarding which Professor Lapworth has made the following observations:*—

"On the whole, it may be asserted with safety that the researches of Mr. Henderson have furnished us with six distinct species of graptolites from the shales of Habbie's Howe, viz. *Monograptus colonus, M. priodon, M. scoticus, M. Flemingi, Retiolites geinitzianus*

* *Trans. Geol. Soc. Edin.*, vol. ii. p. 377.

and *Dictyonema assimile*. The general facies of this group shows at a glance that the containing beds are of Upper Silurian age. The absence of *Monograptus Sedgwicki*, *M. Nilssoni* and other peculiar Llandovery forms forbids us to place the beds in that formation, while the certain presence of *Monograptus priodon* and *Cyrtograptus scoticus*, which are unknown in the Ludlow, equally forbids us to assign them to that formation. They must therefore be considered as of Wenlock age."

At intervals along the eastern slope of Black Hill small exposures of grey slaty shales are to be found, thus indicating their prolongation northwards in the direction of Craigenterrie. Again, at the base of the northern declivity of the hill, the strata present the same lithological characters as at Loganlee, but, so far as known to us, no fossils have been obtained from them.

iii. BAVELAW CASTLE INLIER.

On the northern slope of the Pentland Hills another Silurian inlier extends from the quarries at Bavelaw Castle to the western slope of Black Hill, including a portion of Hare Hill. The strata present uniform lithological characters, consisting of zones of grey slaty shales, with sandy bands or flaggy greywackes and occasional grits. They resemble lithologically those in the lower part of the North Esk—a correlation which is supported by their palæontological evidence. From the quarries at Bavelaw Castle the Geological Survey obtained specimens of *Glassia compressa* (J. de C. Sow.), *Lingula lata* J. de C. Sow., *L. lewisi* J. de C. Sow., together with other forms.

The slope of the range along the northern declivity of Hare Hill exposes in many places grey slaty shales, sandy bands and occasional grits, which are evidently repeated by folding, though their general dip is to the west or W.N.W., at angles varying from 40° to 65°. Two small ravines have laid open fossiliferous strata: the west ravine has furnished specimens of *Acidaspis*, *Glassia compressa* (J. de C. Sow.), *Meristella maclareni* (Hasw.), *Cucullela sp.*, *Theca*, *Orthoceras*; and the east ravine, *Monograptus*, *Retiolites geinitzianus* (Barr.), *Dictyocaris*, *Lingula lewisi* J. de C. Sow. and *Orthoceras*.

In connection with the Upper Silurian rocks of the Pentland Hills, reference ought to be made to the occurrence of numerous blocks of limestone in the greywacke-conglomerate of Lower Old Red Sandstone age in the Logan Burn, about half a mile west of the Loganlee Reservoir, that contain corals and other organisms, a large number of which are Upper Silurian forms. In all likelihood these blocks were obtained from bands of limestone similar to that in the Gutterford Burn, and occurring within the Silurian area of the Pentland Hills.[1]

B. N. P., J. H.

[1] See "Silurian Rocks of Scotland," p. 606, for list of fossils from these limestone blocks.

CHAPTER III.

LOWER OLD RED SANDSTONE.

Rocks of Lower Old Red Sandstone age occupy a considerable area of Sheet 32, extending south-westwards from the southern suburbs of Edinburgh for twelve miles to the edge of the Sheet, and having an average breadth of about two miles. They form the greater part of the Pentland Hills, including the Braid Hills and Blackford Hill to the north, and the projecting spur of Warklaw Hill to the west.*

The researches of Mr. Charles Maclaren on the volcanic rocks of the Pentland Hills deserve special recognition. He was the first to make a detailed investigation of these materials, and to furnish a careful description of their characters and development. He early recognised that the igneous rocks represented a series of slaggy lavas, poured out intermittently with periods of quiescence, during which sediments were laid down. He noticed, moreover, the increasing thickness and variety of the volcanic products when traced from south to north, from which he inferred that the centre of distribution lay somewhere in the northern part of the area. At the same time he ascribed the present linear arrangement of the rocks mainly to their having flowed along a valley trending in a north-east and south-west direction.†

All these conclusions, save the last, were confirmed by Sir Archibald Geikie after his more detailed examination of the area. His investigations led him to the belief that the present distribution of the volcanic rocks is the result of subsequent tectonic movements, followed by prolonged denudation. With regard to the position of the principal volcanic vent, he suggested that it was situated in the low-lying area of the Braid Hills, being led to that conclusion by the disappearance in that area of the marked bedding of the flows, so apparent in the higher ground to the south, and by the difficulty of distinguishing the highly decomposed and frequently brecciated trachyte of the Braid Hills from a fine-grained tuff. His wide acquaintance with the geology of Scotland enabled him to recognise that while the volcanic rocks of the Pentland Hills probably proceeded from a local centre, yet this was only one of many volcanoes which were active in the British Isles at this epoch.

The Lower Old Red Sandstone rests unconformably upon the Silurian rocks, and is in turn unconformably overlain by the Upper Old Red Sandstone. The lower portion is of sedimentary origin and

* Reference should be made to the horizontal section illustrating the geological structure of the Pentland Hills at the foot of the colour-printed edition of Sheet 32.

† "A Sketch of the Geology of Fife and the Lothians, including detailed Descriptions of Arthur's Seat and Pentland Hills," 1st ed, 1839, p. 183.

the upper essentially volcanic, the various subdivisions being given in descending order in the following table:—

(*g*) Carnethy and Hillend group of basalts and basic andesites.
(*f*) Woodhouselee and Braid Hills group of acid andesites and trachytes.
(*e*) Caerketton group of rhyolitic lavas and tuffs.
(*d*) Allermuir group of basic andesites and basalts, with one flow of porphyritic rhyolite near the base and thin intercalations of sediment.
(*c*) Bell's Hill and Howden Burn group of rhyolites, with subordinate conglomerates.
(*b*) Bonally group of basalts and basic andesites.
(*a*) Basement conglomerates and sandstones resting unconformably on Upper Silurian rocks.

The Lower Old Red Sandstone rocks of this area have been affected by powerful earth movements at least twice since the period of their formation. The tectonic features of the Pentland Hills were in large measure determined before Upper Old Red Sandstone time, and were further developed at the close of the Carboniferous period. During the earlier movements the rocks were bent into an arch running north-east and south-west, pitching north, and were traversed by a series of strike faults. The outcrops of the various subdivisions of the group are in general accordance with this structure, but the south-western limb of the fold is almost completely concealed beneath an unconformable covering of Upper Old Red and Calciferous Sandstone strata.

(*a*) BASEMENT CONGLOMERATES AND SANDSTONES.

In consequence of the structure of the range, the Silurian rocks and the overlying basement conglomerates of the Lower Old Red Sandstone are exposed in the southern portion of the area. The latter rest upon any zone of the Upper Silurian formation from the Downtonian group, with its fish beds and conglomerates, down to the Wenlock shales and grits. This indicates the extent to which denudation had proceeded in the area of the Pentland Hills before the deposition of the Lower Old Red Sandstone, but a few miles to the south, near Lamancha, the overlap is continued even farther, and the conglomerates are found reposing on volcanic rocks of Arenig age.

The best exposures showing the unconformable junction of the two formations occur along the course of the Lyne Water at the western edge of the North Esk inlier of Silurian rocks. Here a coarse conglomerate, dipping gently towards the north-west, lies across the truncated edges of the vertical Downtonian strata. The latter include a bed of conglomerate associated with flags and mudstones, which close at hand have yielded the characteristic fossils of the Downtonian fish bed.

Where the Lyne again crosses the margin of the Silurian inlier about a mile farther south the main junction is a faulted one, but a small portion of the Lower Old Red conglomerate is still preserved, close to the fault, resting unconformably on the edges of the "*Trochus* beds" of the Ludlow succession. In all sections to the east and north of this locality, especially those of the North Esk and Monks Burn, the conglomerates dipping to the south-east are

seen to rest on intensely folded greywackes and shales of Wenlock age.

Around the Silurian inlier, near Loganlee, the relations of the two sets of rocks have been obscured, partly by the intrusion of the Black Hill porphyry, which followed the plane of the old unconformity, and partly owing to the subsequent overlap of the Upper Old Red Sandstone.

The best sections of the conglomerates of the basal group are to be found along the courses of the Monks Burn and the North Esk. The following details of the Monks Burn section are quoted from Sir A. Geikie's original account,* the lowest beds occurring at the upper end of the stream:—

	Ft.
Felstone, of Nine Mile Burn †	
Felspathic breccia	
Red sandy conglomerates with felspathic layers	800 to 1200
Hard grits and soft green and yellow sandstones, the whole very generally conglomeratic, but most so towards the base, where there are regular seams of conglomerate..	
Coarse green conglomerate of Silurian grit	100
Grits and sandstones, as before, conglomeratic	200
Coarse greenish conglomerate of Silurian fragments	150
Yellow grit and sandstone	40
Very coarse red conglomerate	250 to 300
Highly inclined Silurian red shales.	

Sir Archibald Geikie further observed that while the general succession of sedimentation is of the same character at all points around the North Esk inlier, yet considerable variations in details can be recognised even in neighbouring sections.

The conglomerates of the group, which are well bedded and composed of well rounded pebbles, are always coarsest at or near the base of the series where they are made up almost exclusively of the debris of Silurian rocks. The locally derived pebbles, however, are much fewer in number than those which resulted from the erosion of older Silurian strata farther to the south. The most abundant pebble consists of greywacke of the type of the Queensberry Grits (Tarranon) which is associated with smaller fragments of the Haggis rock (Caradoc), the radiolarian cherts and the Arenig volcanic rocks. It will be seen that these conglomerates differ from those of the Downtonian group chiefly in their greater coarseness and in their containing so many greywacke pebbles. Further, their natural colour, where unstained, is green, while that of the Downtonian is red. It is interesting to find in the Old Red conglomerates many broken pebbles of quartzite and igneous rock obviously derived from the conglomerates of the older formation. As pointed out by Sir Archibald Geikie, the sandstones and grits associated with these conglomerates have a greenish or grey tint, and frequently it is impossible to distinguish the harder varieties from the subjacent Silurian grits out of which they have in large measure been formed. No pebbles of the volcanic rocks of the Pentland Hills have been obtained from the conglomerates and sandstones of the lower portion of the sequence.

As a general rule the sandstones increase in importance as one

* "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, p. 8.
† Bonally group (*b*) of preceding table (p. 20).

passes upwards in the succession, although conglomeratic conditions recur at intervals throughout, and scattered pebbles frequently appear even in the sandstones. About half-way up from the base of the group pebbles of the basic and acid types of the Lower Old Red volcanic rocks appear and increase in number upwards; at the same time the sandstones show an admixture of felspathic material which forms a conspicuous ingredient in the higher portions of the series.

Round the inlier near Loganlee only the basement conglomerates, free from pebbles of volcanic rocks of the Pentland Hills, are exposed. A good section occurs along the course of the Logan Burn at the waterfall, where the well-bedded conglomerates dip southwards away from the laccolitic intrusion of the Black Hill that have yielded the well-known fossiliferous blocks of limestone,* to which reference has already been made.

In the more northerly inlier, west of Bell's Hill, the conglomerates and sandstones dip to the south-east at 45°. The junction with the Silurian rocks, which is probably a natural one, is here concealed under drift. The original relations of the conglomerate to all the overlying rocks are obscured by faults.

It is evident from the nature of the sediments just described that they were derived from the south and were deposited upon a subsiding area. Many of the conglomerates show an imbricated arrangement of the flatter pebbles similar to that found in torrential flood gravels indicating a transport from the south.

(*b*) BONALLY GROUP OF BASALTS AND BASIC ANDESITES.

The passage of the sediments of group (*a*) into the overlying volcanic rocks can be observed only in the southern part of the area round the Silurian inlier of the North Esk. Here the subdivisions of the volcanic series indicated in the foregoing table (p. 20) are poorly represented when compared with their typical development round the hills of Allermuir and Caerketton. Fortunately it is not difficult to establish the relation between the two areas. The four upper groups (*d*, *e*, *f*, *g*) can be traced continuously from the one region to the other. The Braid Law rhyolites east of the Monks Burn present the same characters as those of Bell's Hill to the north of the Loganlee Reservoir, and although not continuous with them may be confidently referred to the same group (*c*) rather than to the porphyritic acid flow intercalated with the basic lavas of group (*d*). Hence the basic lavas of Bonally, beneath group (*c*) are considered to represent the volcanic rocks which immediately overlie the sediments (group *a*) in the more southerly part of the region.

The Dean Burn that drains the Bonally Reservoir affords an excellent section of basaltic and basic andesitic lava flows (group *b*) inclined gently towards the south-east and separated from each other by their own slaggy surfaces, or by thin partings of basic ash. Some of the lavas are conspicuously porphyritic with tabular plagioclase phenocrysts. The rocks of this group (*b*) with part of the succeeding one (group *c*) are probably repeated in Warklaw and Torduff Hills respectively, by the fault bounding the Bonally outcrop to the west. Here the basaltic lava flows dipping gently towards the south-east

* See page 18.

give rise to conspicuous escarpments on the steep northern face of Warklaw Hill.

In the southern part of the region west of the Braid Law rhyolite the Bonally group of basalts and basic andesites is represented only by a few basic flows alternating with sandstones and conglomerates similar to those of the underlying group (*a*). This attenuation of the lava flows and the occurrence of volcanic material as pebbles in the upper portion of group (*a*) suggest that some of the lower lavas of group (*b*) occurring in the northern area may have been contemporaneous with some of the sediments included in the basal group in the southern part of the chain.

(*c*) BELL'S HILL AND HOWDEN BURN GROUP OF RHYOLITES.

The basic lavas of the Bonally group (*b*) in the typical area near Bonally Reservoir are immediately succeeded on the east by much more acid rocks, the chief type being a light pinkish or yellow rhyolite with very marked platy flow structure which gives rise to conspicuous screes. That this group must consist of several flows ejected at considerable intervals of time is best demonstrated in the section exposed in the Howden Burn that flows past Dreghorn Castle, where several intercalations of sandstone and conglomerate with pebbles of greywacke and rhyolite alternate with these flows. In a general way, though with many irregularities, the inclination of the flow structure is in the same direction as the dip of the sedimentary beds which is steeply towards the south-east. The rhyolites, when followed south-west to Bell's Hill, pass beneath a well-marked bed of conglomerate resembling that of Howden Burn. In both cases the pebbles consist chiefly of greywacke like those of the basement conglomerates, but in this instance there is a considerable number of fragments of basic and acid lavas like the underlying rocks. This feature is best exhibited in the steep wooded hill-slope a little to the west of Kirkton near the head of the Glencorse Reservoir.

A glance at the map will show that the belt formed by the outcrop of the members of this group varies considerably in width, its greatest breadth being about three-quarters of a mile. In the central part of the chain these acid lavas are truncated by the fault which bounds the Black Hill inlier of Silurian rocks. Beyond this dislocation to the south-west there is no reappearance of the rhyolites even in the neighbourhood of the West Kip, where they might be expected to crop out if they originally extended in that direction. As already indicated, there is, in Braid Law, at least one rhyolitic flow which may presumably be referred to this subdivision. It everywhere shows marked fluxion structure and is highly vesicular, the vesicles being drawn out in the direction of the general dip of the strata. The form of the outcrop may best be explained by regarding it as the lenticular cross section of a very viscid lava-flow which is elongated in the direction of dip.

(*d*) ALLERMUIR GROUP OF BASIC ANDESITES AND BASALTS.

In the typical northern area the acid rocks of the Howden Burn group (*c*) are overlain by a succession of basic andesites and basalt

lavas resembling those of the Bonally subdivision (*b*). Towards the base of the series a porphyritic rhyolite lava, of a type elsewhere unrepresented in the Pentland Hills, is intercalated with the basic flows, and has been followed for a distance of about two miles across the head of the Howden Burn and over Capelaw Hill. At a slightly higher horizon a band of fine volcanic grit was traced by Sir Archibald Geikie for over three miles along the valley occupied by the Glencorse and Loganlee Reservoirs, and is well exposed on the roadside to the north of the latter reservoir. At their greatest development round Allermuir the members of this group must be over 1000 ft. in thickness. Crowned everywhere by the light coloured rhyolitic lavas and breccias of the succeeding group (*e*), these dark basic rocks give rise to the great escarpment of the Pentland Hills from Allermuir southwards to the East Kip. Like the members of the other subdivisions they are attenuated when followed south-westwards towards the Kip Hills (Plate II.).

(*e*) CAERKETTON GROUP OF RHYOLITIC LAVAS AND TUFFS.

The rhyolites of this subdivision closely resemble the acid lavas of the Howden Burn group (*c*) already described; but in this case they are associated with an important development of acid tuffs and breccias. The rhyolites are sometimes nodular as in Caerketton and usually exhibit fluxion structure often much involved and accompanied with brecciation due to flow. The fragmental material varies greatly in texture and is sometimes very fine-grained. Near the summit of the track between Scald Law and Carnethy, a remarkable white-coloured tuff shows in section numerous rings resembling pisolite, which may originally have been hollow spheres. During a visit to this locality Dr. H. J. Johnston-Lavis compared them to the hollow spheres formed by raindrops falling upon the fine powdery ashes of Vesuvius, and suggested that they might have had a similar origin.

This group attains its greatest development in Castlelaw, north of the Glencorse Reservoir, where there are several alternations of lava and tuff. Southwards from this hill, fragmental rocks preponderate and underlie the lavas. In Caerketton, however, the breccias occur at the top of the group, and a similar sequence is observable still farther north in the isolated exposure east of the cross-roads at Fairmilehead. Beyond this locality the Caerketton group is no longer represented, and the rocks of group (*f*) appear to succeed directly to those of group (*d*).

(*f*) WOODHOUSELEE AND BRAID HILLS GROUP OF ACID ANDESITES AND TRACHYTES.

The rocks of this group, which are less acid and more varied than those of the preceding subdivision, consist of hornblende- and mica-andesites, associated with trachytes. The dominant type may be regarded as acid andesite, quite distinct in character from the pyroxene andesites and basalts which form the greater portion of the volcanic series of the Pentland Hills. They are readily recognised in the field by their earthy texture and light grey colour.

THE PENTLAND HILLS FROM GLENCORSE RESERVOIR, LOOKING SOUTH-WEST.

When weathered, they yield the typical claystones of the older authors.

The members of this group form a belt of varying width along the dip slopes of the hills from Caerketton in the north-east to Walstone in the south-west.

The interpretation of the sequence to the north of Caerketton has been greatly facilitated by Dr. Flett's determination of the Braid Hills claystone to be trachyte, resembling the type that occurs at Woodhouselee and still farther to the south-west in the South Black Hill, thus indicating the northern prolongation of the members of this group. But the continuity of their outcrop north-east from Woodhouselee is interrupted by a fault, running from a point near Boghall by Swanston to Fairmilehead, which truncates the acid rocks of groups (*e*) and (*f*), and shifts their outcrops farther north on the downthrow side (see Sheet 32). By means of this dislocation the basic andesites of Hillend Hill (group *g*), to be immediately referred to, are brought into contact with the acid andesites and trachytes of Woodhouselee, W.N.W. from Boghall. Again between Swanston and Caerketton, a hornblende-andesite has been recognised, which must lie between the rhyolitic rocks already mentioned as occurring near the cross roads at Fairmilehead and a pyroxene andesite belonging to group (*g*). This hornblende andesite is regarded as the continuation of the Woodhouselee group on the east or downthrow side of the fault.

In the Braid Hills, where the members of this group bend round an anticlinal fold, only one type of trachytic lava has been observed. The rock is very fine grained and exhibits a platy fluxion structure, inclined at all angles in various directions, and much broken up by lines of subsequent crushing. In view of its decomposed condition and its fine texture, it was doubtless difficult to determine under the microscope the true character of this rock. It is not surprising that Sir A. Geikie regarded it as a fine-grained pyroclastic rock, especially as both fluxion breccias and crush breccias are exceedingly common in these hills.

(*g*) CARNETHY AND HILLEND GROUP OF BASALTS AND BASIC ANDESITES.

The members of this group form the highest portion of the volcanic pile exposed in this part of the Pentland Hills. There is no evidence, however, that they represent the natural top of the series, as these lavas, where not truncated by the great boundary fault that brings them into conjunction with the Carboniferous strata, are unconformably overlapped by the Upper Old Red Sandstone.

Two well-known types occur in this group, the porphyritic basalt of Carnethy and the fine-grained andesite of Blackford Hill. The dip of the successive flows is well seen on the spurs of the Pentland Hills rising above Hillend and at various localities farther to the south-west. A cross section is visible in the road cuttings in the Glencorse valley below the reservoir, where the slaggy upper and under surfaces of the flows are very conspicuous, though the rocks are much decomposed and reddened.

Blackford Hill, which forms the northern limit of the anticline, seems to be mainly carved out of a single massive flow, underlain by a thin bed of agglomerate, seen at the north-west corner of the hill, and overlain by a lava of Carnethy type.

Volcanic Vents and Intrusive Igneous Rocks of Lower Old Red Sandstone Age.

A few small volcanic vents, filled chiefly with fragmental material, rise through the basic lavas of the Allermuir group (*d*) in the northern portion of the area near Swanston, and were first described by Sir Archibald Geikie.* One of them forms a hillock west of Swanston Cottage and is filled chiefly with a breccia containing basic and acid material pierced at its western end by a mass of rhyolite like that of the Caerketton group to which the vent probably contributed. The much smaller vent forming a little knoll immediately to the south is filled with a coarse breccia composed chiefly of various andesitic fragments, while still farther south there is a third orifice narrow and elongated in an east and west direction like a fissure vent. It is filled partly with agglomerate consisting of acid and basic fragments and partly with a mica porphyry resembling the adjacent rhyolitic lava flow.

Between Swanston and Hunter's Tryst and in the field to the west, ash is exposed which probably fills a fourth vent of large size. The pyroclastic material is fine-grained and made up almost entirely of rhyolite fragments. A few acid intrusions occur near the Swanston volcanic necks, which, though they cannot with certainty be connected with any one of these orifices, have evidently risen along the same line of weakness.

Again to the north of Bell's Hill, near the hill path between Currie and Glencorse, a boss of pink felsite is exposed which may represent a plug filling a vent, though not associated with any pyroclastic material. Its intrusive character is inferred from its unbedded appearance, its lack of flow structure and its degree of crystallization. In all these features it contrasts strongly with the rhyolites of Bell's Hill (group *c*), and presents a great resemblance to the Black Hill felsite. It may, however, represent a stock or vent from which the upper members of this group may have proceeded.

By far the best known intrusion in the Pentland Hills is that which forms the Black Hill, consisting of a somewhat dappled flesh-coloured micro-granite or felsite. At its southern end and close to the path leading from Loganlee to Bavelaw the felsite is seen to rise more or less vertically through the Silurian shales and to spread nearly horizontally over their truncated edges. Higher up the hillside, a patch of the intensely hardened basement conglomerate of the Lower Old Red Sandstone is seen resting upon the igneous rock and can be traced westwards until it joins the main mass of the conglomerate. It is evident that the felsite has intruded itself as a laccolite along the unconformable junction line between the Silurian and Lower Old Red rocks. Apophyses of the felsite in the form of dykes and sills can be seen traversing the

* "Ancient Volcanoes of Great Britain," 1897, vol. i. p. 324.

hardened conglomerates in the waterfall at the foot of the Logan Burn on the other side of the hollow which is locally known as "Habbie's Howe," but not marked on Sheet 32.

An intrusion of a markedly different character from that just described is exposed in the Lyne Water at the western side of the North Esk inlier of Silurian rocks. Although it is too much decomposed for accurate determination its granitoid structure distinguishes it from the Carboniferous intrusions of the district. It recalls in many respects the basic modifications found near the edges of some of the granite masses in Galloway. It has considerably altered the basement conglomerate of the Lower Old Red Sandstone into which it has been injected. Although in this area the evidence is indefinite, it is probable that this plutonic mass is of a slightly later date than the lavas of the Pentland Hills.

Dykes.—Some decomposed lamprophyre dykes traverse the rocks of the Silurian inliers in a north-east and south-west direction. Three examples intersect the fossiliferous Wenlock shales in the small quarry south of Bavelaw Castle in the Black Hill inlier. Other instances appear in the Gutterford Burn, a tributary of the North Esk, where they cut the highly fossiliferous rocks of Wenlock age, near the locality famous for having yielded such a fine suite of Eurypterids. Sills of a similar rock, too small to be shown on the one-inch map, occur in the bank of the Quarrel Burn at the western base of Braid Law, where they are intruded into the sediments intercalated with the lavas of group (*b*) of the Lower Old Red volcanic sequence. Their period of intrusion seems to have been about the close of the volcanic episode of the Pentland Hills.

Physical Conditions.—As already indicated, the nature of the conglomerates found at the base of the Lower Old Red Sandstone series and their relations to the underlying Silurian rocks clearly show that the materials derived from the denudation of the folded Silurian strata of the Southern Uplands were being transported from the south on to the area now occupied by the Pentland Hills. Further, it is probable, if not certain, that the latter region sank while the Southern Uplands were being elevated. This subsidence and accumulation lasted for a long time before the manifestation of volcanic activity, and they continued during the greater part, if not the whole, of the period of accumulation of lavas and tuffs still preserved within the area.

From the evidence obtained during the revision of the area (see pp. 25 and 36) it is clear that the vent from which the volcanic materials were discharged did not occupy the site suggested by Sir Archibald Geikie. Still it is obvious that an important centre of eruption must have lain somewhere near the northern end of these hills, for there is a gradual attenuation of all the groups when traced towards the south-west. There is little evidence bearing on the question whether the orifice lies in the concealed ground to the east or west of the present exposures of the volcanic rocks. If we may suppose that the group of small vents in the neighbourhood of Swanston, first observed by Sir Archibald Geikie, may have been parasitic cones near the main vent, we may infer that the latter lay somewhere in the neighbourhood of Colinton.

The boss or plug of felsite described as lying to the north of Bell's Hill and ending across the eroded lavas and ashes, may represent a minor orifice; but if so, it could only have supplied one of the acid volcanic zones. The felsite of the Black Hill is in a different category, as it is manifestly a laccolite spreading out along the plane of unconformability. It may not improbably represent an abortive attempt to set up a vent and thus may be regarded as belonging to the volcanic phase.

From analogy with other areas (Cheviot Hills, Ochils, Lammermuirs), although the present one affords no definite evidence on the point, it is probable that the granitoid intrusion of the Lyne Water and the thin lamprophyre dykes represent the plutonic and hypabyssal phases of the igneous history of this region following successively upon that of surface extrusion.

No other volcanic district in Scotland furnishes such an excellent illustration of the alternation of markedly different types of lava. The striking feature of the records of vulcanicity in the Pentland Hills is the succession of basic and acid groups rather than of individual flows,—a feature which was clearly recognised by Sir Archibald Geikie. B. N. P.

CHAPTER IV.

PETROGRAPHY OF THE VOLCANIC ROCKS OF THE PENTLAND HILLS.

The descriptive petrography of the rocks of the Pentland Hills has been investigated by Professor Jameson* and Charles Maclaren,† but the only account of them from a modern standpoint is that contained in Sir Archibald Geikie's "Ancient Volcanoes of Great Britain" (vol. i.), which is accompanied by analyses executed by Mr. James S. Grant Wilson. The materials used in the preparation of this chapter are principally the large collection of rocks and slides formed by Sir Archibald Geikie, but include also many additional rocks collected during the revision of the mapping. It will be seen that the general results are entirely confirmatory of Sir Archibald Geikie's work.

The difficulties met with in describing the petrography of the volcanic rocks of the Pentland Hills are considerable, and arise mainly from the very imperfect state of preservation of the hand specimens. The rocks are undoubtedly much decomposed. Fresh specimens of many of the lavas will probably never be obtained. Yet there are a few of the basic igneous rocks that still show the original ferromagnesian minerals (with the exception of olivine, which is never visible in good preservation in any Pentland rock). In most of them, however, the ferromagnesian minerals have entirely decayed, and usually also the felspars have been completely replaced by secondary aggregates of various kinds. The mode of decomposition and the nature of the secondary products—which depend largely upon the nature of the original minerals, usually give indications of the character of the mass, and modes of weathering in the field-outcrops are of some assistance. Sir A. Geikie, in view of these difficulties, has had large numbers of sections cut from some of these rocks, hoping, no doubt, in this way, to obtain a safe basis for an opinion. But only a very limited degree of success has attended this step, except where it proves that similar rocks, in a like condition of degeneration, occupy a considerable area, and may be mapped as a single mass.

Three types of degeneration are found in these igneous rocks—so well defined and so easily distinguishable as to serve as a rough and ready index to a full classification. They are based on the essential and original nature of the rocks, and hence afford a means of establishing a subdivision into three broad classes.

I. The more *basic* rocks are charged with iron oxides—mostly hematite, but also in some part limonite. Calcite is the only other common product. So complete is the alteration that not only have the ferromagnesian minerals vanished, but serpentine and chlorite

* *Memoirs of the Wernerian Society*, 1818, vol. ii. p. 178.

† "A Sketch of the Geology of Fife and the Lothians, 1839."

also are rare, while epidote and zeolites are seldom or never seen. The dark red colour of the screes and weathered outcrops of this series is an unmistakable field-indication of their distribution.

II. The most *acid* rocks become silicified. They change to red hornstone-like or even jaspery masses. Under the microscope their prevalent constituent is secondary quartz, which is intimately mixed with other derivative minerals, such as kaolin. Limonite and hematite give them a pale red colour. Calcite is unusual in these rocks, and chlorite is equally rare. Secondary muscovite after the felspar is found mainly in the intrusive acid rocks (Black Hill granite porphyry). The pale colour and flinty character of this group serve perfectly to indicate them in the field.

III. Decomposition of the third type results in the formation of "claystones." These are grey, lilac or buff, but their colour depends in large measure on the amount and state of chemical combination of the iron they contain. If hematite is very abundant they are red, if it is very scanty they are creamy or yellow; limonite makes them various shades of brown. They are soft and easily scratched, but are not friable. Often they are spotted with small pale spots, irregularly scattered or grouped in bands. Pseudomorphs after porphyritic felspars are often seen in them, but not usually in abundance, and the rocks are rarely vesicular. Green areas of chlorite after ferromagnesian minerals are seldom to be found in these claystones, and it is a somewhat remarkable fact that while they never show fresh hornblende or augite they occasionally contain scales of black, well-preserved biotite.

Secondary quartz rarely appears in these rocks in any quantity, and they are never extensively silicified: this indicates that they do not belong to the acid group. Neither is calcite at all a frequent ingredient of them, which shows that they were originally poor in the more basic soda-lime felspars and pyroxenic minerals. They form, in fact, a group of *intermediate* rocks, which must have consisted principally of felspars belonging to the more acid species of plagioclase and to orthoclase.

The microscope shows their composition to be exceedingly simple. In addition to scattered grains of iron oxide, they contain only aggregates of fine scaly kaolin and muscovite after felspar. With very thin sections it is clear that the scaly kaolin and mica are surrounded by a network of another mineral which is colourless, and has a rather high double refraction. This is secondary quartz, the presence of which is explained by the liberation of silica which takes place when the more acid felspars are kaolinised. This quartz forms a sponge, the interstices of which are occupied by kaolin, and when the conditions are favourable it can be established that over small areas the quartz is in optical continuity, so that the structure is a modification of that which is known as "poikilitic," but in a secondary aggregate (p. 36).

Other evidence regarding the original nature of these rocks will be given later, when the consideration of their least altered representatives is taken up (p. 36).

Chemical analyses of the rocks of the Pentland Hills are of great interest and value. Five are given by Sir Archibald Geikie.* They

* "Ancient Volcanoes of Great Britain," vol. i. pp. 274 and 278.

show that, with some modification, the weathered rocks retain to a surprising degree the chemical characteristics of the original lavas, and in cases where mineral degeneration is very far advanced, the bulk composition is not necessarily greatly changed. The elements have entered into new combinations, but have only to a slight extent been carried away and replaced by others of a different nature. In regions like the Pentland Hills where the rocks have so decayed that their original minerals are only to be inferred from the shapes and composition of the pseudomorphs they leave, the petrologist finds that chemical investigation is of the greatest possible value in supporting or negativing the evidence furnished by microscopical examination.

The Basalts.

In the Pentland Hills, olivine basalts occur in considerable numbers, mostly as lava flows, but probably also as intrusions. Most of them are of porphyritic structure; only in a few instances are the rocks ophitic or sub-ophitic. In all cases they are greatly decomposed; their olivine has been replaced by limonite and hematite, which often form dense, opaque pseudomorphs, but at other times have a clear centre composed of calcite, with sometimes an admixture of quartz or of serpentine. In other rocks they consist of dark-brown "iddingsite." The felspars also are often replaced by calcite and kaolin, and are stained with oxides of iron, but are sometimes fairly well preserved, and show the characteristic multiple twinning. Fresh augite has been seen in very few of the slides; it is practically always replaced by calcite, limonite, quartz, and chlorite. It is not always easy to distinguish between the pseudomorphs after pyroxene and those after olivine; but when the latter mineral is at all abundant, the characteristic outlines of its crystals are always observable, and give a clear indication as to the nature of the original rock. Many of these basalts are vesicular, their steam cavities being filled with chlorite, calcite, iron oxides or various forms of agate and chalcedony.

Warklaw Hill Basalts.—The rocks of Warklaw Hill and the north-west side of Torduff Reservoir (group *b*) are all basaltic, and include some of the most basic lavas of the whole series. They are in a state of advanced decomposition, the felspars being the only minerals which are still preserved, but the pyroxene and olivine can both be identified from the outlines of their pseudomorphs. The olivines were numerous and large, and are represented mostly by calcite and iron oxides, but also by iddingsite and serpentine. The structure is markedly porphyritic, as felspar, augite and olivine all occurred as phenocrysts lying in a finer groundmass, which is now entirely converted into an aggregate of calcite, iron oxides and other secondary products, and is often so ferruginous as to be quite opaque. A few small steam cavities are visible in the sections; they are filled with calcite, chlorite, chalcedony and iron oxides. Both fine-grained and coarse-grained basalts occur in this series, and the former may show pronounced fluxion structure. Sir Archibald Geikie gives an analysis of one of these rocks.*

One or two flows of olivine basalt, not unlike those of Warklaw

* "Ancient Volcanoes of Great Britain," vol. i. p. 274.

Hill, are found on the Dean Burn above Bonally, intercalated among andesites, and a decomposed sub-ophitic dolerite occurs in the old quarry on the east of Bonally Pond. Along the strike of these rocks there is a knoll in the fields south of Dreghorn Castle consisting of very similar decomposed basalt with many opaque pseudomorphs after olivine.

The Allermuir and Loganlee Basalts.—The Allermuir group (*d*) of andesitic and basaltic rocks stretches from the vicinity of Lothian Burn through Swanston, south-west along Allermuir to Loganlee Reservoir. At its base it includes a considerable number of olivine basalts, which repeat all the essential features of those of Warklaw Hill. They are very completely decomposed and are coloured dark brown by abundant secondary oxides of iron, though a few are dark green from the prevalence of chlorite. All contain much olivine and augite, though represented only by pseudomorphs; their felspar is sometimes fairly well preserved but is usually deeply stained with hematite and chlorite, and permeated with calcite. The groundmass is so obscured with secondary deposits as to be undecipherable under the microscope. Vesicles filled with calcite, hematite, chlorite and chalcedony are common in these rocks, though never forming so large a proportion of their bulk as in the augite andesites.

A minute description of these rocks is needless owing to their very decomposed state. The collection includes specimens from a small quarry at Swanston Cottage, from the north side of Shearie Knowe, and from the Green Craig. At the roadside on the west of Loganlee Reservoir similar olivine basalts are exposed, both at the north and at the south end of the loch. These rocks have the porphyritic structure usual in lava flows, but ophitic and sub-ophitic varieties (which may be intrusive) occur also at Shearie Knowe and at the north-west corner of Loganlee Reservoir.

Several miles to the north-east, in the Mortonhall Golf Course, there is a small ridge of dark olivine dolerite at the east end of the Elf Loch, and a similar rock is found in the old quarry north-west of Meadowhead.

Basic rocks recur again among the lavas of the Hillend group (*g*) and are found also on the east side of Carnethy. The Hillend lavas are dark-red rocks with abundant plagioclase felspar and many pseudomorphs after olivine, but they are not of exactly the same type as those of Warklaw Hill and Loganlee. Their olivine crystals are smaller, less numerous and less conspicuous, and their felspar predominates to such an extent that it is doubtful whether they may not be regarded as olivine-bearing augite andesites. They are separated, however, without difficulty from the augite and hypersthene andesites (a few of which occur along with them), and it has seemed best to include them among the olivine basalts. In these rocks also the felspar remains in part undecomposed. Iron oxides, calcite and chlorite impregnate them strongly: porphyritic structure is universal, and steam cavities occur frequently, though the rocks are not highly vesicular.

The well-known "porphyry" of Carnethy, which carries large pale-green phenocrysts of labradorite in a fine dark-green matrix, has been included among the diabase lavas by Sir A. Geikie, and this seems reasonable in view of the basic character of the rock as

revealed by the analyses cited by this author.* The low percentage of silica (51·16) relegates the rock to the category of basalts. The microscopic sections show little olivine, in small corroded crystals entirely changed to limonite and serpentine (iddingsite). The augite has passed into chlorite, calcite and limonite. Felspar, belonging to a basic variety of labradorite, is the main component of the rock, and occurs in large tabular repeatedly-twinned phenocrysts and numerous small laths of a second generation in the groundmass. The rock contains scattered vesicles filled with chlorite, calcite and chalcedony, and though much decomposed, is one of the freshest of the basic lavas of the Pentlands.

Andesites.

A considerable variety of andesitic rocks is found in the Pentland Hills, ranging from augite and hypersthene andesites, very dark in colour, to pale biotite and hornblende andesites. The former group is not without difficulty separated from the basalts, into which it passes by a gradual transition, but in every case in which a rock shows a notable percentage of olivine it has been assigned to the basalts. The andesites are not less numerous than the basalts; they form probably the greater part of the volcanic series. The majority are in the same condition as the basalts above described, and their investigation resolves itself into a determination of pseudomorphs.

Dark basic augite andesites occur on the east side of Torduff Reservoir and in the Dean Burn (group *b*), alternating with the basalts above described and resembling them closely in appearance and in state of decomposition. Many of these rocks contain a few small crystals of olivine, but these are less numerous than in the basalts, and there is much more felspar. Some of these lavas are vesicular. In the Dean Burn there are also dark andesites which show pseudomorphs of bastite after idiomorphic hypersthene, a mineral easily recognised by the shape of its pseudomorphs. The association of basic andesites with olivine basalts is not confined to this locality, and as a rule the andesitic rocks preponderate in the upper part of such an assemblage, while the basalts are more numerous below.

Similar augite andesites — which possibly contained a little olivine—are found in the White Hill plantation above Bonally and on the north of Shearie Knowe. On the high ridge between Allermuir and Caerketton (group *d*) a dark red andesite occurs in a very fair condition of preservation. It bears much resemblance to some of the Cheviot Rocks (Yetholm, etc.) and contains pseudomorphs after hypersthene. The porphyritic felspars are still fresh, and the groundmass has originally contained a fair percentage of glass (hyalopilitic). This is a type of andesite which recurs in all the Lower Old Red volcanic areas. Far to the south-west vesicular augite andesites form the summits of the East Kip and West Kip Hills. In the lavas of Hillend (group *g*) there are augite and hypersthene andesites mixed with the Hillend basalts, and, like them, much decomposed.

The Blackford Hill Type of Andesite.—The well-known rock of

* "Ancient Volcanoes of Great Britain," vol. i. p. 274.

Blackford Hill (group *g*), extensively quarried for road metal, is a dark grey finely crystalline and non-vesicular andesite, which weathers with a reddish colour and is intersected by veins of jasper and chlorite. It contains few porphyritic crystals, usually small plagioclase felspars, but occasionally also biotite or augite, though always decomposed. The rock consists mainly of small, lath-shaped, simply-twinned felspars, with a well-marked fluxion arrangement. Between them lie minute grains of calcite mixed with chlorite, obviously secondary after original augite. Iron oxides, apatite and zircon also occur. Fresh augite or biotite never appear in the sections, and the former presence of biotite is inferred only from the shape of certain pseudomorphs which are covered with dusty magnetite. A similar rock, equally decomposed, is found in Cayie-side Quarry, north-east of Swanston, and at Busie Law, Swanston, there is an andesite of somewhat similar character but containing many plates of pale brown biotite still perfectly fresh. Their edges are not corroded, and this rock differs somewhat from those of Blackford Hill and the Braids, though resembling them in more than one feature.

An analysis of the Blackford Hill andesite has been executed by Dr. Pollard, and is quoted below. Frankland's analysis of the Busie Law rock * is not very satisfactory, but is given for comparison. In both cases the alkalies are high and the silica comparatively low. The felspar must be andesine, oligoclase and orthoclase. In many respects the andesite of Blackford Hill recalls the mugearites, but it differs from these by the absence of olivine.

	Andesite, Blackford Hill. Anal. W. Pollard.	Andesite, Busie Law. Anal. Frankland.
SiO_2	57·53	52·00
TiO_2	·91	..
Al_2O_3	16·47	18·76
Fe_2O_3	4·42	9·38
FeO	3·23	1·14
MnO	·17	..
(Co,Ni)O	tr.	..
CaO	6·16	9·23
SrO	nt. fd.	..
BaO	nt. fd.	..
MgO	1·32	2·04
K_2O	2·09	1·66
Na_2O	4·13	4·17
Li_2O	tr.	..
H_2O 105° C.	·20	2·68
H_2O above 105° C.	·82	
P_2O_5	·63	0·32
CO_2	2·47	..
Cl	nt. fd.	..
S	tr.	..
	100·55	101·38

* Sir A. Geikie, "The Ancient Volcanoes of Great Britain," vol. i. p. 274.

Biotite and Hornblende Andesites and Trachytes.

In the Pentland Hills, rocks belonging to these categories have a fairly wide distribution and are of considerable importance, but many of the rocks are too much decomposed to render a minute discrimination possible. This is especially true when the felspars have been kaolinised, for though the nature of the ferromagnesian minerals can often be inferred from the shapes of their pseudomorphs, the outlines yielded by sections of the monoclinic and triclinic felspars are too much alike to yield any clue to the original species when none of its optical characters can be observed. These rocks weather in a very characteristic fashion. Kaolinisation, which results in the production of claystones, is their typical mode of degeneration. They range in colour from pale yellow or pale grey through various shades of lilac to brown or bright red and often mottled. This characteristic is sufficient to distinguish them in the field from both the basic and the acid rocks.

Biotite Andesites.—Some of the red porphyritic lavas which occur among the rhyolites of Capelaw contain much plagioclase and biotite, and may be best described as biotite dacites.

Very similar specimens, though in much worse preservation, occur in several other localities. In no case, however, are their felspars fresh, and it is not impossible that some of them may belong to the trachytes. Near Fairmilehead, on the road leading south from Edinburgh, there are decomposed hornblende biotite andesites, with many black-rimmed pseudomorphs after hornblende and biotite, and specimens were obtained in Torduff Hill and at Torphin Crags which seem to belong to the same category.

Trachytes.—The members of this group, like the biotite andesites, are usually much decomposed. The best preserved are those of Woodhouselee (group *f*). In the quarry north of the mansion house of Woodhouselee a biotite trachyte is found (312). It is a dark grey or reddish grey rock with phenocrysts of sanidine and fresh biotite. In the microscopic section, the felspars, though somewhat weathered, show simple twinning under polarised light; a few are polysynthetic and belong to oligoclase: the felspar phenocrysts are sometimes $\frac{1}{4}$ in. in diameter. The biotite is in thin dark brown hexagonal plates, which have black "corrosion borders" but still preserve well their original crystal outlines. In addition to the larger biotites, small scales of the same mineral occur in the groundmass, together with many elongated sanidine microliths arranged with their long axes parallel in winding fluxion strains. These are surrounded by a fine-grained turbid substance which was originally a finely crystalline felspathic base, but is now partly replaced by kaolin and quartz. A few crystals of zircon, iron oxides, apatite and ill-defined stains of limonite are also present in the slides, but calcite is apparently absent. The silica percentage of this rock has been determined by Mr. Barrow as 63·3.*

Other specimens of biotite trachyte, in which the felspars can still be identified were obtained in the south-east side of Castlelaw, about 100 yds. north of Castle Knowe. The rock is very similar to

* Sir A. Geikie, "The Ancient Volcanoes of Great Britain," vol. i. p. 279.

that of Woodhouselee, containing porphyritic sanidine and biotite in a fluidal felspathic groundmass, but many minute irregular patches of quartz are scattered through the section. Most of these are secondary, and it does not seem likely that quartz was present as an original ingredient. The tendency to silicification is more marked in the trachytes than in the biotite and hornblende andesites. The collection contains several other rocks from the same vicinity (south face of Castlelaw) which may possibly belong to this group, though their felspars are much decomposed and their groundmass contains secondary quartz. They are all pale rocks which have been porphyritic and highly felspathic, and have contained phenocrysts of corroded biotite. Some of them may belong really to the rhyolites and dacites, but none show porphyritic quartz, and the finely granular quartz in their groundmass has probably been set free by the decomposition of their felspars.

The Braid Hills Rocks.

The purplish or lilac "claystones" of the Braid Hills (group *f*) are among the most decomposed in the whole area, and it is only after examining a large suite of sections both of them and of others of similar type in the Pentland Hills that we are able to formulate definite conclusions regarding their original nature. Sir Archibald Geikie considers that they are for the most part fine volcanic dust derived from the explosion of felsitic or orthophyric lavas.* Bands of breccia do occur in several parts of the Braid Hills, but the microscopic sections do not support the hypothesis that the rocks are chiefly of this nature. Wherever they are not entirely decomposed it is easy to make out in them the remains of an originally crystalline structure, and though, on the whole, the specimens are very like one another, yet it is possible to trace belts of rock which maintain the same character along the strike. Thus the rocks extending from the hotel to Liberton Tower are different from those of the south part of the Braids golf course, and these again are not exactly the same as those which form the ridge of the Buckstone and Mortonhall golf course.

These claystones consist almost entirely of felspar and of its decomposition products. The felspar rarely gives its characteristic reaction to polarised light. It is very frequently replaced by kaolin, muscovite and secondary quartz. Although the last-named mineral is constantly present it is never very abundant, and there is less silicification than in the majority of rhyolites and trachytes in the Pentlands. Occasionally strings and veins of quartz may be detected in the slides. Calcite is also not common, but some specimens (for example, that of which an analysis is quoted by Sir Archd. Geikie †) contain it in fair amount.

Biotite is the only other important primary mineral. It is sometimes fresh but has always suffered from corrosion and has darkened borders. Usually, however, it is entirely decomposed, and its nature can only be assumed from the form of its pseudomorphs. Apatite, often of the turbid pleochroic variety which is common in volcanic

* "Ancient Volcanoes of Great Britain," vol. i. p. 324.
† *Op. cit.* vol. i. p. 278.

rocks, zircon and iron oxides in numerous small grains are also present in the slides. Very frequently the rocks of the Braid Hills are porphyritic, the biotite forming thin irregular plates 1 millimetre in diameter and the felspars being of varying size, but mostly small and perfectly formed. Some of these rocks, however, show pseudomorphs after crystals of felspar not less than 2 millimetres in diameter. Only rarely and in the best preserved specimens can the nature of the groundmass be inferred from the appearances in microscopic section. It is sometimes of the "trachytic" type, fine-grained, fluidal, with small felspar microliths and grains of iron oxide; at other times it has consisted of fairly large (·2 or ·3 mm.) grains of felspar without good crystalline form.

It is clear that these rocks belong either to the biotite trachytes or biotite andesites. Their high percentage of felspar, the small amount of ferromagnesian minerals, the scarcity of secondary quartz and calcite, and the porphyritic and fluidal structure are all in harmony with this suggestion.

Rocks practically identical in character with those of the Braids and Mortonhall are found in Torduff Hill (group *c*).

Sir Archibald Geikie cites an analysis by Prof. E. Frankland of the rock from the Braid Hills, but it seemed of sufficient importance to have a typical specimen, as fresh as possible, from there and from Mortonhall analysed in the laboratory of the Geological Survey by Dr. Pollard. The three analyses are given below—

	(Hornstone), Braid Hills. Anal. Prof. Frankland.	Trachyte (decomposed), Braid Hills Quarry. Anal. W. Pollard.	Trachyte (decomposed), Mortonhall. Anal. W. Pollard.
SiO_2	64·73	65·82	63·02
TiO_2	..	·40	·43
Al_2O_3	17·01	16·37	15·50
Fe_2O_3	2·35	2·06	4·81
FeO	..	·18	·13
MnO	·24	·16	·10
(Co,Ni)O	..	tr. (?)	tr.
CaO	4·19	2·74	2·67
BaO	..	·03	nt. fd.
MgO	·66	·51	·62
K_2O	3·27	3·48	3·96
Na_2O	3·75	4·24	4·46
Li_2O	..	tr.	tr.
H_2O 105° C. ..	2·78	·72	1·00
H_2O above 105° C.		1·85	1·49
P_2O_5	..	·21	·16
S	·26	nt. fd.	·03
CO_2..	*	1·84	1·82
	99·24	100·61	100·20

These analyses confirm the inferences drawn from microscopic examination of the rock. The silica percentage is by no means abnormal for the trachytes, so that there is little probability that the rock has been silicified. The alkalies are high, especially when we remember that the type of decomposition, which the rock exhibits, namely kaolinisation, is characterised by a general diminu-

* This rock is stated to contain also 0·13 per cent. FeO and 2·42 per cent. CO_2. Sir A. Geikie, "Ancient Volcanoes of Great Britain," vol. i. p. 278.

tion of these constituents. The lime and magnesia are both very low, especially in the rocks analysed by Dr. Pollard, while the high percentage of water indicates a considerable amount of decomposition.

Rhyolitic and Felsitic Lavas.

Rocks belonging to this group occur on several horizons in the Pentland Hills, one being that of the Howden Burn and Bell's Hill (group *c*), while another extends from Caerketton through Castlelaw to Walston (group *e*) near the south edge of the Sheet. They occur also near Woodhouselee. They are recognised without difficulty in the field by their pale pink or reddish colour and their flinty appearance. The best examples in the collection from the lower series are fine-grained, non-porphyritic, flesh-coloured felsites from Capelaw and the glen between Bell's Hill and Harbour Hill. The microscopic sections show that some of these rocks consist of a fine slightly granular turbid felsitic material, without trace of spherulitic or fluxion structures, and containing no porphyritic ingredients. Many of the specimens from Capelaw show small lath-shaped felspars in a fluidal groundmass. These rocks have undergone secondary silicification but this is not sufficient to mask their original characters. They have been and are still compact crypto-crystalline felsites and rhyolites.

In the upper group (*e*) the banded and spotted pinkish felsite which forms Caerketton Crags is well known. It is accompanied by acid breccias and tuffs, and under the microscope shows considerable silicification. In places, the slides consist of fine crypto-crystalline felsitic material, but elsewhere this is replaced by a mosaic of rather coarse secondary quartz in irregular grains, which are rendered turbid by innumerable specks of iron ores and kaolin and the minute cavities they contain. In the striped varieties the silicification is often most pronounced along certain bands, and when the rocks are spotted it is usual to find that the round spots consist entirely of a secondary quartz mosaic. These spots (which are usually from $\frac{1}{8}$ to $\frac{1}{16}$ in. in diameter) are the remains of spherulites which have been replaced by silica. Traces of the original radiate structure persist. They have been arranged in sinuous lines parallel to the fluxion. The rock, when unaltered, was a spherulitic felsite probably with bands of more or less vitreous character alternating with others which were crypto-crystalline, but it may have been a true obsidian. Here and there it contains small pseudomorphs after porphyritic felspar, but no trace of quartz phenocrysts appears in the slides. No pseudomorphs after biotite or other ferromagnesian mineral can now be detected; but grains of iron ore occur, many of them in the centres of the spherulites.

The rhyolites and acid breccias of Caerketton can be followed towards the south-west into Castlelaw, along the west face of which they are well seen. Their general character is the same throughout, and the secondary silicification is equally pronounced in both localities. In their decomposed condition the possibility that dacites and silicified trachytes occur among them cannot be excluded, and this indeed seems highly probable. Many of the Castlelaw specimens show a fine fluxion-banding, but none of the specimens collected are

so rich in spherulites as those of Caerketton. Remains of porphyritic felspars, entirely replaced by kaolin and quartz, occur sparingly. The matrix is partly a fine felsitic substance, partly a mosaic of turbid secondary quartz grains. The original felspar both of matrix and phenocrysts is usually represented only by the products of its decomposition, but in some of the rocks small lath-shaped felspars of a second generation are abundant. In certain slides they are mostly acid plagioclase, in others there is a large proportion of sanidine. In Braid Law (group *c*), near the southern extremity of the volcanic series, the rock is a reddish yellow or salmon-coloured rhyolite with marked fluxion-banding and occasional drawn out vesicles. It is one of the best examples of the group in the Pentland Hills, as it contains many cavities filled with clusters of quartz crystals and also phenocrysts of decomposed sanidine felspar. Its matrix is a felsitic or, in some places, microcrystalline quartzo-felspathic aggregate which still preserves most of its original characters. No doubt it was somewhat coarser-grained than the Caerketton and Castlelaw felsites; it is far less completely silicified, and was probably less acid, as in many features it shows some resemblance to the trachytes. A second generation of felspar was present in small prisms in the groundmass, and some obscure pseudomorphs probably represent original biotite.

Near Woodhouselee, along with the trachyte (group *f*) above described, well-preserved and characteristic rhyolites occur. One of these, from a quarry ¼ mile W.S.W. of Woodhouselee House, has been analysed by Dr. Pollard. The analysis is that of a typical rhyolite, and as the felspars are in fairly good preservation, there is no reason to suspect that the rock has been greatly silicified. It contains porphyritic crystals of sanidine, oligoclase, and brownish green biotite (the last without black corrosion borders) in a fluidal matrix of small elongated laths of sanidine (and some acid plagioclase) mixed with little irregular grains of quartz and fine, red, dusty hematite. Patches of secondary chalcedonic silica and of kaolin appear here and there, occupying what were probably irregular cavities, but the rock was not highly vesicular. Secondary silica is deposited also along the cleavage planes of the biotite. Magnetite, zircon and apatite are the only accessory minerals. The matrix gives the impression that it was in large measure crystalline, and that there was originally little vitreous base. Although some of the quartz may be secondary it seems unreasonable, in view of the chemical composition of the rock, to place it among the trachytes.

Rhyolite from quarry at edge of fir plantation ¼ mile W.S.W. of Woodhouselee House. (Analysis by Dr. Pollard.)

SiO_2	72·78
TiO_2	·19
ZrO_2	·03
Al_2O_3	12·86
Fe_2O_3	3·14
Cr_2O_3	nt. fd.
V_2O_3	nt. fd.
Carry forward ..	89·00

Brought forward ..	89·00
FeO	·26
MnO	·09
(Co,Ni)O	?tr.
CaO	·92
BaO	·05
MgO	·83
K_2O	4·14
Na_2O	2·31
Li_2O	tr.
H_2O 105° C.	1·05
H_2O above 105° C.	1·89
P_2O_5	·14
S	?tr.
Cl	?tr.
	100·68

There is also a number of rocks in the Pentland Hills closely allied to the rhyolite of Woodhouselee, but very extensively silicified and their original nature is far from clear. Viewed in thin section, in ordinary light they present the appearance of *trachytes*, as they show the unmistakable outlines of felspar crystals, which formed phenocrysts in a fine-grained reddish groundmass. (Plate IX. Fig. 1.) Between crossed nicols, however, the felspars prove to be entirely converted into feebly polarising aggregates of kaolin, while the whole groundmass consists of irregular granules of quartz filled with kaolin, hematite and other cloudy decomposition products. (Plate IX. Fig. 2.) Obviously there has been decomposition accompanied by extensive silicification. Although these rocks never show porphyritic quartz, it seems advisable to regard them all as *rhyolites*, though it is an open question whether some trachytes may not be included among them.

Good examples of these rocks come from Camphill Quarry and from Scald Law (group *e*). The top of South Black Hill (group *e*) consists of a similar rock with porphyritic felspars entirely kaolinised and many dark-rimmed pseudomorphs after corroded biotite. The groundmass is felsitic and impregnated with secondary silica.

Intrusive Acid Rocks—Microgranites.

The laccolite of the Black Hill consists of a pale red microgranite, the matrix of which is a microcrystalline aggregate of small irregular grains of quartz and weathered felspar with scales of muscovite which are probably partly secondary. In this lie small phenocrysts of orthoclase, quartz and biotite, but these are far from numerous. The most characteristic feature of this rock, however, is the presence of many porphyritic crystals and crystal groups of very fine micropegmatite. Many of these have the outlines of felspar and show simple twinning. A few have the shapes of pyramidal quartz. A full account of this rock has already appeared in the *Transactions of the Edinburgh Geological Society.**

In Cleugh Maid, between Bells Hill and Harbour Hill, a felsite occurs which is so like that of the Black Hill in all essential respects that it is probably also intrusive. It contains less porphyritic quartz and felspar, but shows the characteristic micropegmatite

* J. S. Flett, *Trans. Geol. Soc. Edin.*, 1899, vol. vii. p. 483.

phenocrysts, and has a similar microgranitic matrix. It is quite unlike the rhyolitic lavas above described.

There are also intrusive veins of fine red felsite (see Sir A. Geikie, "Ancient Volcanoes of Great Britain," vol. i. p. 278, for analysis) in Targeith Knowe and Shearie Knowe, both localities being not far west from Swanston Cottage. J. S. F.

CHAPTER V.

UPPER OLD RED SANDSTONE.

THERE is no direct evidence of important differential movement during the deposition of the conglomerate and volcanic rocks of the Lower Old Red Sandstone series of the Pentland Hills beyond the general subsidence of the area during their accumulation.

In the great interval of time, however, between the close of the Lower Old Red Sandstone period and the deposition of the Upper division of this system, crustal movements, resembling those which brought the Silurian period to a close, supervened and developed an anticlinal fold in the older rocks, traversed by a series of strike faults. Subsequent denudation stripped the anticline to its very core, and carved out the main features of the southern part of the range. It is not surprising, therefore, that the various igneous rocks of the district have suffered to such an extent from decomposition, since they have twice formed portions of land surfaces. Wherever the junction is clear the strata that immediately overlie the volcanic rocks and sediments of Lower Old Red Sandstone age belong to the Upper Old Red Sandstone. The unconformity between the two is complete for, when the base of the younger series is followed round the hills, it is found in contact with successive members of the older rocks. At the Black Hill it rests upon the intrusive felsite as well as upon the inlier of Upper Silurian rocks. The relation between the conglomeratic beds of the upper part of the Upper Old Red Sandstone and the volcanic rocks, notably the lavas of Warklaw Hill, shows that the escarpments of the latter had largely assumed their present form at this early date, and the outlier which occurs at the Bonally Reservoir furnishes similar evidence. Owing to the inequality of the surface upon which the deposits accumulated, their thickness varies rapidly from point to point. They reach their maximum development at the northern extremity of the arch of the Pentland Hills in the southern suburbs of Edinburgh, and in the Cairn Hills towards the southern edge of the map they must be about 1000 ft. thick. In the intermediate region, however, only a few feet of calcareous conglomerates and sandstone, belonging to the highest portion of the series, intervene between the Lower Old Red volcanic rocks and the lowest members of the Cementstone group at the base of the Carboniferous formation.

The main mass of the Upper Old Red Sandstone is composed of quartzose sandstones of a reddish colour, though frequently the tint is very pale. They are often friable and are associated with reddish and greenish sandy mudstones or marls. In the sediments there is usually more or less calcareous matter often in the form of concretions, which frequently unite to form more or less continuous bands of cornstone. Evidence of contemporaneous erosion is to be

found especially in the Edinburgh district where the Craigmillar sandstones are characterised by bands of conglomerate studded with fragments of grey and white cornstone and with less conspicuous galls of green and red clay and small lumps of sandstone. These conglomerates usually contain fragments of the volcanic rocks of the Pentland Hills, together with pebbles derived from the Lower Old Red Sandstone conglomerates, and various Silurian rocks of the Southern Uplands, more especially the radiolarian cherts.

Neither on palæontological nor on lithological grounds has it been found possible to subdivide the series as developed in this region. Only one zonal form (*Holoptychius nobilissimus*), determined by Dr. Traquair, has been obtained, and the occurrence of cornstones throughout the group supports the view that the whole of the rocks in the present area belong to the Dura Den zone, which, in accordance with the researches of Dr. Traquair, is regarded as the highest subdivision of the formation.

The Upper Old Red Sandstone has shared in the folding of the Carboniferous strata in this region: the axis of plication coinciding with the anticlinal axis established at the close of Lower Old Red Sandstone time. As in the former case, the pitch of the anticlinal fold in the Edinburgh district is to the north. Erosion has laid bare a fringe of Upper Old Red Sandstone round the northern end of the older rocks and along their western margin. Their absence on the eastern side of the chain is due to the great fault that brings the overlying Carboniferous strata into conjunction with the Lower Old Red Sandstone.

A few traverses across the fringe will serve to illustrate the development of the series in the present area.

Liberton to Craigmillar and Salisbury Craigs.—The junction of the Upper Old Red Sandstone with the older rocks to the west of Liberton is everywhere concealed under superficial deposits. The lower beds exposed by the roadside and in the fields to the north-west of Liberton Church consist of conglomerate made up chiefly of subangular débris mostly derived from the volcanic rocks of the Pentland Hills. The village is underlain by a series of friable red sandstones sometimes conglomeratic, with red marls and cornstones which dip to the east of north at angles of about 20°. From this point to Craigmillar the same direction of dip is generally maintained, though the inclination varies and gradually becomes less. Friable red sandstones are seen in the first few exposures as far as the road that passes Little France. Eastwards the Craigmillar type of sedimentation supervenes, the sandstones are lighter in colour and harder and coarser in texture, constantly passing into conglomerate, whose chief constituent is a fine-grained white or grey cornstone resembling many of the cementstone bands of the Cementstone division of the Calciferous Sandstone series. Fragments of vein quartz, volcanic rocks of the Pentland Hills, radiolarian cherts, and occasionally a few reddened derivative pebbles of quartzite also occur. The pebbly beds in Craigmillar Quarry, which were referred to the Carboniferous system during the first survey, yielded to Mr. Tait some fragmentary fish remains, among which Dr. Traquair observed a scale of *Holoptychius nobilissimus*, thus confirming Mr. Goodchild's correlation of these strata with the Upper Old

Red Sandstone. The passage of the Craigmillar sandstone upwards into the Carboniferous rocks is concealed beneath superficial deposits, but in the branch line to Raeburn's Brewery, a little to the east of the cross roads at Craigmillar, a dark coaly layer, intercalated among yellow sandstones and bluish shales, yielded Carboniferous plant remains, thus fixing the position of the boundary line between the two formations within a few yards. A bore for water, put down at Craigmillar, pierced the Upper Old Red Sandstone rocks to a depth of 1800 ft. without reaching the old floor. The number of breweries at Craigmillar indicates the importance of this group of rocks as a source of permanently hard water well adapted for brewing purposes.

Sandstones, grits and fine conglomerates belonging to this group underlie the intrusive sheet of dolerite in Salisbury Crags. In previous editions of the Geological Survey map (32) they were referred to the Calciferous Sandstone series, but the late Mr. J. G. Goodchild * suggested that they are of Upper Old Red Sandstone age in virtue of the character of the sediments, and especially of the cornstone associated with them. During the revision of Arthur's Seat Dr. Peach detected in the grits exposed at the side of the Queen's Drive minute fragments of fishes, which were regarded by Dr. Traquair as portions of dendrodont teeth, though not specifically determinable. Permission having been granted by H.M. Office of Works in Scotland to charge the rock-exposure with dynamite, a mass of material was set free, which, when broken up by Mr. Macconochie and Mr. Tait, yielded conclusive fossil evidence.† Among the fragments Dr. Traquair identified teeth and scales of *Holoptychius* and a piece of a scale of *Holoptychius nobilissimus*.‡ This discovery subsequently lead to the search for fish remains in the Craigmillar sandstone already referred to, and in the grits at Clubbiedean Reservoir.

Blackford Hill to Craiglockhart Station. — In a small quarry about 200 yds. to the east of Blackford Hill Station on the Suburban Railway, the local base of the Upper Old Red Sandstone was once well exposed, and may yet be seen resting on the Blackford Hill andesite. The sandstone is red, friable and flaggy, with a few pebbles of andesite, and dips gently towards the north-west. Between Blackford Hill Station and a point to the west of Morningside Road Station no solid rock is exposed along the suburban line, but at several places a little to the north of the railway, fine red conglomerate, sandstones and cornstones have been met with from time to time during building operations. About half a mile to the west of Morningside Road Station, where a dolerite intrusion is shown on the map, a good section of the upper part of the series is met with in the deep railway cutting which continues to within a short distance of Craiglockhart Station. Here we find an association of sandstones and conglomerates as in the upper part of the series at Craigmillar, but in the present case the sandstones are softer and redder, and are intercalated with a greater

* "Some Recent Exposures of Rock in Edinburgh," *Trans. Edin. Geol. Soc.*, vol. viii. pp. 1–8.

† Peach and Horne, "Base-Line of the Carboniferous System round Edinburgh," *Brit. Assoc. Rep.* for 1904, p. 546.

‡ "Summary of Progress," *Mem. Geol. Sur.* for 1904, pp. 89 and 123.

proportion of marl, the latter frequently containing cornstone concretions. The more argillaceous beds were evidently subjected to desiccation at the time of their formation, and hence they are traversed in many cases by a plexus of sand dykes which are in continuity with overlying beds of sandstone. The evidence of contemporaneous erosion is strikingly shown at the base of more than one of the conglomeratic bands that transgress the underlying finer beds, fragments of which are found embedded in the conglomerate. Fully 500 ft. of these strata, dipping steeply northwards, are visible in this section, but their relation to the Carboniferous rocks is obscured by the Colinton fault, which brings down highly inclined dark shales and ironstones of Wardie and Granton type into conjunction with the red sandstones. On both sides of this fault there is evidence of dislocation by minor faults, and the vertical downthrow, great though it be, does not represent all the displacement, as many of the fault-faces indicate considerable lateral movement.

Between Craiglockhart and Bonally there must be a rapid thinning out of the group against the steep northern face of the old land surface. Whether the Carboniferous strata actually rest upon the Lower Old Red volcanic rocks at Bonally as represented on the map cannot be definitely ascertained, but about half a mile to the south-west, between the Clubbiedean and the Torduff Reservoirs, where the exposures are clear, only a few feet of conglomerate and sandstone referable to the Upper Old Red Sandstone intervene between the volcanic rocks and the Carboniferous shales and cementstones. Indeed the evidence obtained from the fragmentary fish remains collected by Mr. Tait from these grits is, according to Dr. Traquair, not conclusive as to their age, although they have been included in the Upper Old Red Sandstone on account of their resemblance to the Craigmillar sandstones which have yielded fragments of *Holoptychius*.

Along the fringe of Upper Old Red Sandstone, extending southwestwards to Easter Bavelaw, conglomerates and sandstones are seen at intervals, overlain by Lower Carboniferous strata. Still farther to the south-west the group rapidly swells out to form the East and West Cairn Hills and the Colzium Hill. Throughout this area the conglomeratic nature of the deposit is not conspicuous. Even at the base the conglomerate is only a few feet thick. An interesting point is illustrated in the Logan Burn above Loganlee, where the basement beds rest upon the coarse conglomerate of Lower Old Red Sandstone age already described. The discordance between the two is clearly marked, and the few pebbles found in the upper beds are manifestly derived from the older conglomerates. In many cases they have been broken and partially rounded a second time before they were embedded in the sandy matrix. A band of cornstone lying near the base of the sandstone was formerly worked for lime not far to the west of Bavelaw Castle. Traces of this band also occur in the Logan Burn, and, still farther to the south-west, what appears to be the same band has evidently been worked near the southern base of the West Cairn Hill in the Ravendean and the Baddingsgill Burn as recorded by Maclaren.*

* "Geology of Fife and the Lothians," 2nd ed., 1866, p. 233.

Most of the sandstones that form the Cairn Hills are pale in colour, especially where weathered. Their upper limit is defined by the overlying variegated clays and cementstones of Ballagan type exposed in the Dean and Baad Park Burns, tributaries of the Water of Leith. Beyond these streams the boundary line is conjectural, owing partly to the absence of the cornstone and partly to the covering of superficial deposits.

Sandstones apparently belonging to this group occupy a small area at Selms, about a mile to the south of Mid-Calder. They have long been known by a cornstone that has been extensively worked at that locality. It is a grey concretionary limestone in three layers, separated by bands of hard reddish sandstone with courses of calcareous marls, and is overlain by white sandstone that has been quarried along the slope to the east of Selms. Though no fossil evidence has been obtained from these sandstones, yet their general similarity to the Upper Old Red Sandstone of the Cairn Hills, and the fact that they are succeeded by shales and cementstones of Ballagan type, tend to support this correlation.*

Conditions of Deposition.—The irregular surface upon which the Upper Old Red Sandstone of this area was laid down has already been referred to, a feature common to a much wider region. It is probable that the sediment was derived from the north, for the great amount of silica and often of felspar in the grits, and the presence of mica in the finer-grained beds, point to a metamorphic area invaded by plutonic masses as their source. It seems certain that the rocks were deposited in water on an area undergoing subsidence, but the complete absence of the remains of ordinary marine forms of life, together with the evidence of desiccation and contemporaneous erosion on so many different horizons, tend to support the theory that these deposits are the products of inland seas. The cornstones, which were evidently of the nature of chemical precipitates, also favour this view, pointing, as they appear to do, to frequent concentration of the water in which the deposits accumulated. During the periods of desiccation, winds may have played a direct part in arranging some portions of the deposit.

B. N. P.

* There is a small development of the highest beds of the Upper Old Red Sandstone below the Castle Esplanade on the slope facing Johnstone Terrace, which is referred to on p. 56 of this memoir.

CHAPTER VI.

THE CARBONIFEROUS SYSTEM.

History of Investigation.

Before the detailed mapping of the Carboniferous Rocks of Mid-Lothian and West Lothian was first undertaken by the Geological Survey in 1857, important contributions had been made to our knowledge of the main divisions of the system and their general arrangement.

Towards the beginning of last century, Mr. R. Bald, an engineer, produced a valuable series of papers relating to this branch of inquiry, many of which were published in the *Transactions of the Wernerian Natural History Society*. In 1819 he published a horizontal section across the Mid-Lothian coal-field, and showed the correct form of the basin much as it is known to-day, and also the two great groups of coals with the barren band of sandstones (Millstone Grit) between them. The lower group was termed by him the Edge Coals on account of their high inclination on the west side of the basin, and the upper group the Flat Coals (now known as the Coal Measures) because they lie at gentle angles near the centre of the syncline.* He erroneously inferred, however, together with Maclaren, who followed him, that the Flat Coals and intervening strata had been deposited after the Edge Coals had been raised to their present inclined position.

In 1836 a classic paper appeared in the *Transactions of the Royal Society of Edinburgh*,† by Dr. Hibbert, on the limestone of Burdiehouse—one of the important stratigraphical horizons in the lowest division of the system. He furnished a horizontal section showing that this band underlies the true marine limestones of the Lower Limestone group, and a vertical table illustrating the sequence of the Loanhead coals (Edge Coals). He called attention to the absence of undoubted marine remains in the Burdiehouse limestone, and to the occurrence in it of plants, entomostraca and fish remains, chiefly of palæoniscid fishes, from which he inferred that the limestone was of fresh-water origin.

In his volume on the "Geology of Fife and the Lothians,"‡ published in 1839, Maclaren advanced a classification of the Carboniferous rocks of the Lower Basin of the Forth, in which he introduced the term "Calciferous Sandstones," which is now restricted to the lowest division of the system. As originally used by that investigator, the term comprised not merely the strata of this division,

* "Additional Observations on the Coal-Field of Clackmannanshire and Description of the Absolute Shape or Form of the Coal-Fields in Great Britain," *Mem. Wernerian Nat. Hist. Soc.*, vol. iii. p. 123.

† *Trans. Roy. Soc. Edin.*, vol. xiii. p. 169.

‡ "Geology of Fife and the Lothians," 1839, p. 72.

but also part of the overlying Lower Limestone group and part of the underlying Upper Old Red Sandstone.

In 1840 an important advance was made by the publication of a memoir on "The Mid-Lothian and East Lothian Coal-Fields,"* by D. Milne (Dr. Milne Home), which contained a series of horizontal sections, tables of vertical sections taken from mines and bore-journals, together with a map showing the outcrops of the main coal seams, limestones and faults. He corrected the erroneous inference of Bald and Maclaren by pointing out that there is a normal sequence from the Edge Coals to the Flat Coals in the centre of the basin. On the other hand, he erred in correlating the coal-bearing strata of the Mid-Lothian and East Lothian basins with the Carboniferous rocks in the valley of the Tweed, thereby placing them far below the Coal Measures of Newcastle, even below the Scar Limestones of the north of England.

In 1859 the first edition of Sheet 32 was published by the Geological Survey, which was followed in 1861 by a memoir on "The Geology of the Neighbourhood of Edinburgh," the work having been done by H. H. Howell and A. Geikie. The distribution of the various subdivisions of the system, the outcrops of the important coal seams and limestones, together with the direction and downthrow of the faults, are represented on the map and described in the memoir. In his description of the Mid-Lothian basin Mr. Howell correlated for the first time the Coal Measures in the centre of the syncline with the Coal Measures of Newcastle and Durham, and the thick sandstones of Roslin and Hawthornden with the Millstone Grit of England.† This correlation was confirmed by the palæontological evidence presented in the Appendix‡ by Mr. Salter. In view of the subsequent classification of the Carboniferous rocks on the basis of the plants found in them, the remarks of that sagacious palæontologist regarding the Carboniferous plants from the Edinburgh district are significant. He observed that, "as a rule (not without exceptions), few species of plants pass from the Coal-beds beneath the Mountain Limestone into those above them. The subject has yet to be more fully worked out for Britain; but on the Continent the Lower and Upper Coal-bearing measures are well distinguished by their fossils."§

Another noteworthy feature of this memoir is the classification of the contemporaneous and intrusive igneous rocks of Carboniferous age presented by Sir A. Geikie‖—a subject which, in 1859, had already engaged his attention in his attempt to arrange the igneous rocks of Scotland in chronological order.¶ At a later date (1879) he published a valuable monograph on the "Carboniferous Volcanic Rocks of the Basin of the Firth of Forth," in which he directed special attention to their microscopic characters.**

A further contribution to our knowledge of the development of

* *Trans. Roy. Soc. Edin.*, vol. xiv. p. 253. This paper, with an important supplement, was subsequently issued separately.

† "The Geology of the Neighbourhood of Edinburgh," 1861, pp. 103–105.

‡ *Op. cit.* pp. 144–151.

§ *Op. cit.* p. 144.

‖ *Op. cit.* pp. 17–29, 47–62, 111–120.

¶ *Rep. Brit. Assoc.* (*Aberdeen*, 1859), p. 106.

** *Trans. Roy. Soc. Edin.*, vol. xxix. p. 437.

coal in the lower basin of the Forth was made in 1864 by Mr. Landale, the mining engineer, in his "Description of the Large Coal-Field under the Firth of Forth."* He referred to the evidence in proof of the continuity of the Fife and Lothian coal-fields, and indicated on a chart of the Firth of Forth the probable lines of outcrop of the Carboniferous Limestone and the supposed extent of coal-field. He inferred that "these assumed lines give us an area of 140 square miles of coal-field from shore to shore of the Firth, containing an average of 130 ft. thick of coal nearly entire, except the few small workings along the shore already enumerated." †

In 1875 Prof. Judd gave his interpretation of the volcanic history of Arthur's Seat. Instead of referring the extrusive materials to two distinct periods of eruption, as originally suggested by Maclaren and supported by Edward Forbes and Sir A. Geikie, he contended that they mark successive stages in the evolution of one volcano during the Calciferous Sandstone period.‡ In the sequel it will be shown that this view has been confirmed by the Geological Survey during the revision of Arthur's Seat.

In the same year Mr. John Henderson communicated to the Edinburgh Geological Society a paper "On the Wardie and Granton Series of Sandstones and Shales," in which he advanced evidence to prove that the sandstones of Granton and Craigleith underlie the Wardie shales. He also announced the discovery of marine fossils at Woodhall, Drumsheugh, Craigleith and Granton near the base of the Wardie shales.§

In 1877 Mr. R. Etheridge, Jun., then palæontologist on the Scottish staff of the Geological Survey, embodied the results of a systematic study of the invertebrate fauna of the Calciferous Sandstone series of the Edinburgh neighbourhood in a paper which he contributed to the Geological Society of London. The author gave an outline of this branch of inquiry up to that date, furnished descriptions and figures of numerous species from Mr. Henderson's collection, appended remarks on the first appearance of many of these fossils, and indicated the occurrence of three or four marine beds in the Calciferous Sandstone in addition to that mentioned by Salter at Clubbiedean. In relation to the first appearance of species he showed the occurrence, low-down in the Calciferous Sandstone series, of fossils, which afterwards attain their greatest development in, and become characteristic of the Carboniferous Limestone series.‖

When the oil-shale areas of Mid and West Lothian were first mapped by Sir Archibald Geikie on behalf of the Geological Survey in 1857, not one of the existing oil-shale fields in the Calciferous Sandstone series was as yet being worked. The subsequent development of these fields necessitated a re-survey of those shale-bearing areas, which was successfully accomplished between 1884 and 1887 by Mr. H. M. Cadell, when attached to the staff of the Geological Survey. The results of that re-survey were embodied in a second edition of Sheet 32, issued in 1892.

In 1885 Mr. Cadell communicated a brief description of the

* *Trans. Roy. Soc. of Arts*, vol. vi. p. 341.
† *Op. cit.*, p. 353.
‡ *Quart. Jour. Geol. Soc.*, 1875, vol. xxxi. p. 131.
§ *Trans. Edin. Geol. Soc.*, vol. iii. p. 24.
‖ *Quart. Jour. Geol. Soc.*, 1878, vol. xxxiv. p. 1.

results of his re-examination of the shale-fields to the meeting of the British Association at Aberdeen in a paper entitled "Recent Advances in West Lothian Geology." * He indicated the position of the various oil-shales then proved in the course of the mining operations, and furnished estimates of the thickness of the subdivisions of the Calciferous Sandstone series. Again, in 1901, he published a detailed account of the geological structure of the various shale-fields in the Lothians and in Fife, illustrated by horizontal sections, in the *Transactions of the Institute of Mining Engineers* † and also in the *Transactions of the Edinburgh Geological Society.* ‡ Subsequently in 1906, a detailed description of the geology of the oil-shale fields of the Lothians was completed by Mr. Wilson with the assistance of Mr. Cadell and published by the Geological Survey as Part I. of an economic memoir dealing with the oil-shale industry of Scotland.

Reference must be made to the special opportunities enjoyed by Mr. Goodchild, during his long residence in Edinburgh when in charge of the Geological Survey collections in the Industrial Museum, of examining temporary exposures of rock sections and the cores of bores put down for water supply within the city. The valuable information thus acquired was generously placed at the disposal of the Survey before the revision of Sheet 32 was undertaken in 1902. Part of the evidence obtained by him is set forth in two papers communicated to the Edinburgh Geological Society.§ One of the important features of these observations was the definite stratigraphical horizon assigned to the Abbeyhill shales at the top of the volcanic rocks of Arthur's Seat and to the grouping of these shales with the Ballagan beds (the Cementstone group) of the west of Scotland.

In his address to the Royal Physical Society, Edinburgh, in 1893,‖ Dr. Kidston summarised the results of his detailed researches on the flora of the Carboniferous rocks, and gave a table showing the vertical distribution of Carboniferous plants. On this basis he arranged the strata in two divisions—(1) lower, comprising the Calciferous Sandstone and Carboniferous Limestone series; (2) upper, including Millstone Grit and Coal Measures. He mentioned that the plants in the Millstone Grit are all specifically distinct from those which preceded them, and that we here meet with a new flora —a flora having a facies of its own, whose general characteristics are common to the plants of the succeeding Coal Measures.

A similar classification of the Carboniferous Rocks of Scotland was reached independently by Dr. Traquair from his prolonged study of the fossil fishes obtained from them. On various occasions he drew attention to the fact that different assemblages of estuarine fishes characterise the two great divisions of the Carboniferous system ¶ as defined by Dr. Kidston. In his great memoir "On

* *Rep. of Brit. Assoc.*, 1885, Trans. of Sections, p. 1037.

† "The Oil-Shale Fields of the Lothians," *Trans. Inst. Min. Eng.*, 1901.

‡ "The Geology of the Oil-Shale Fields of the Lothians," *Trans. Edin. Geol. Soc.*, vol. viii. pt. i. p. 116.

§ "Notes on a Bore-hole through the Rocks of the Calton Hill," *Trans. Edin. Geol. Soc.*, vol. vii. p. 259. "Some Recent Exposures of Rock in Edinburgh," *op. cit.* vol. viii. p. 2.

‖ *Proc. Roy. Phys. Soc. Edin.*, 1892–94, vol. xii. p. 183.

¶ *Proc. Roy. Soc. Edin.*, 1889–90, vol. xvii. pp. 386, 387; also *Geol. Mag.*, 1884 (3), vol. i. p. 121.

the Distribution of Fossil Fish Remains in the Carboniferous Rocks of the Edinburgh District," published in 1903,* he furnished a list of the fishes from nearly all the subdivisions of this formation together with a table showing their vertical distribution. The leading facts are thus summarised by him—

"We have in the estuarine beds of the Lower Carboniferous series of the central valley of Scotland a fish fauna of which many of the species persist through thousands of feet of strata, and must therefore have lived for a very long time without change in their specific characters. Then, after the Millstone Grit, poor in fish remains, is passed, we come to a new fauna, from which nearly all the Lower Carboniferous species, and with them also a number of genera, have disappeared, their place being taken by an Upper Carboniferous assemblage, which in its main features is characteristic not only of the Coal Measures of Scotland, but of the Lower and Middle Coal Measures of England, extending also into the Transition series of the latter country.

"Why this sweeping change took place about the time of the Millstone Grit we do not know; neither can we as yet explain the peculiar fish fauna of the Lower Carboniferous estuarine beds of the south of Scotland. It remains to be seen whether future investigation, for which there is abundance of room, will throw light upon those questions concerning which we are so much in the dark."

In 1898 Mr. Gunn, who mapped a large part of the eastern area of Northumberland on behalf of the Geological Survey, contributed an important paper to the Geological Society of Edinburgh on the Correlation of the Lower Carboniferous Rocks of England and Scotland.† He endeavoured to show that the Lower Limestone group about Dunbar and round the Mid-Lothian coal-field does not represent any part of the Great Scar Limestone of Yorkshire, but is the equivalent of the upper part of the Yoredale series of Phillips, while the Edge Coals and Upper Limestones of Mid-Lothian represent a series of beds, which in Yorkshire and Northumberland lie above the true Yoredale series of Phillips, and which were included by him in the Millstone Grit. From this correlation Mr. Gunn contended that the lower part of Phillips' Yoredale series, together with the Scar or Mountain Limestone of Yorkshire, is represented in Scotland by the Calciferous Sandstone series. This paper is illustrated by four vertical sections showing the sequence of strata below the Millstone Grit at Ingleborough, in Wensleydale, North Northumberland and in Scotland.

The correlation advocated by Mr. Gunn was not accepted by Dr. Wheelton Hind,‡ who, in a paper communicated to the Edinburgh Geological Society at the same meeting, maintained that the fauna of the Carboniferous Limestone and the Yoredale series of the Wensleydale area are identical, and that this fauna is largely that of the upper and lower divisions of the Carboniferous Limestone series of Scotland, the essential differences being due to the fact that the Scottish beds were laid down nearer land, and hence the fauna has a larger number of sublittoral forms than obtains farther south. He held that the Yoredale series is only a local phase of the Carboniferous

* *Trans. Roy. Soc. Edin.*, vol. xl. p. 687.
† *Trans. Edin. Geol. Soc.*, vol. vii. p. 361.
‡ *Ibid.* p. 332.

Limestone, and that the Carboniferous Limestone series of Scotland is really the equivalent of the whole "massif" of limestone of Derbyshire, the Great Scar and Yoredale series of Wensleydale and the divisions of rocks in Northumberland called the Carbonaceous and Calcareous Divisions by the Geological Survey.

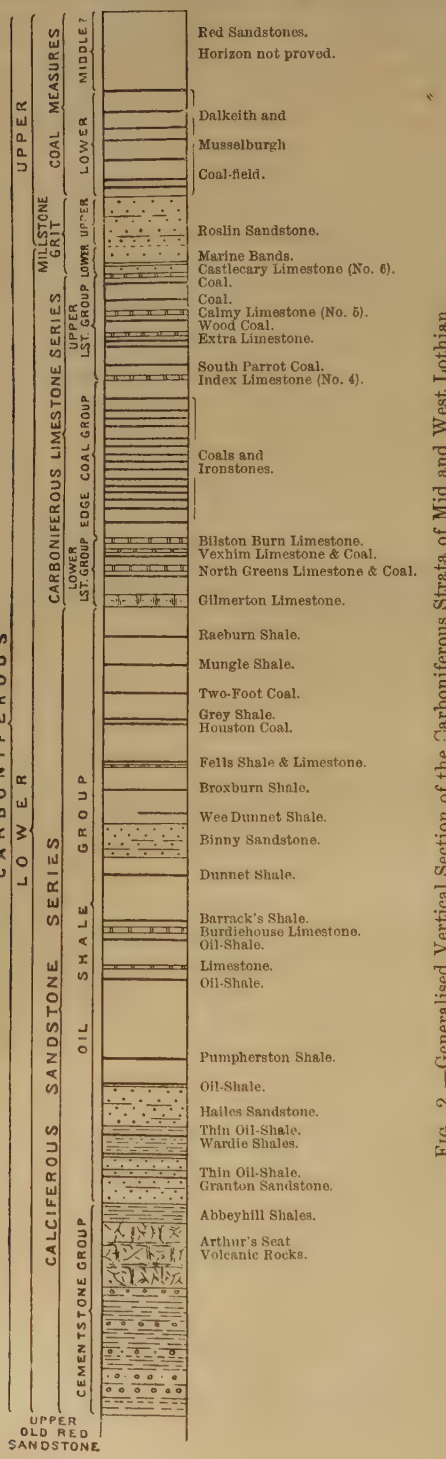

Fig. 2.—Generalised Vertical Section of the Carboniferous Strata of Mid and West Lothian.

The valuable researches of Dr. Vaughan, who has established a definite palæontological sequence in the Carboniferous Limestone of the Bristol area, based mainly on the distribution of the corals and brachiopods, has given a renewed impetus to this branch of inquiry. An exact correlation with the English sequence has not as yet been established in Scotland. It would appear, however, that the Lower Limestone group of Scotland may represent the upper portion of the *Dibunophyllum* zone (Upper Visean) of Bristol, and that certain marine bands in the Cementstone group beneath the Fell Sandstones of Liddisdale may be the equivalents of the *Zaphrentis* and *Syringothyris* zones (Tournaisian) of the Avon section.*

A palæontological "find" of great interest and importance was made by Mr. Tait while collecting plants to be determined by Dr. Kidston in connection with the probable boundary line be-

* "Palæontological Sequence in the Carboniferous Limestone of the Bristol Area," *Quart. Jour. Geol. Soc.*, 1905, vol. lxi. pp. 181–307.

tween the Upper and Lower Carboniferous Rocks. He found certain fossiliferous bands in the basal portion of the Millstone Grit, in Mid-Lothian, Lanarkshire and Stirlingshire, charged with lamellibranchs, brachiopods, and other marine organisms, which are associated with Lower Carboniferous species of plants. When this collection was submitted to Dr. Wheelton Hind for examination, he found a lamellibranch fauna, of which quite 50 per cent. of the species were new to Europe, but which resembled very closely the lamellibranch fauna of the Coal Measures of Nebraska and Illinois of North America.*

In this historical account of the more important contributions to our knowledge of the Carboniferous strata and associated igneous rocks of the area under description, reference must be made to the researches of Dr. Falconer on "The Igneous Geology of the Bathgate and Linlithgow Hills." † His results relating to the sequence and distribution of the igneous rocks may thus be briefly summarised: (1) the lavas of the Bathgate Hills are olivine-bearing from base to summit of the series, and are pierced by a few contemporaneous intrusions of similar material; (2) the Bo'ness lavas form a group entirely distinct from the lava-zones of the Bathgate Hills; (3) the volcanic zones are crossed by a later connected series of dykes and sills probably of Palæozoic age. The detailed results of the microscopical and chemical analysis of the rocks were set forth in a subsequent paper published in 1906.‡ The distinctive feature of these researches was the separation of the intrusive igneous rocks into two distinct groups according to age, a classification which was reached independently by the Geological Survey during the revision of the area, before the publication of his researches.

At a later date R. Campbell and A. G. Stenhouse described a striking example of an east and west quartz-dolerite dyke cutting the well-known sill of picrite in the island of Inchcolm.§

In the accompanying vertical section (Fig. 2) the various subdivisions of the Carboniferous system in Mid-Lothian and West Lothian are represented in descending order. It further shows the new division line which has been drawn by the Geological Survey at the base of the Granton Sandstone between the Oil-shale group and the Cementstone group of the Calciferous Sandstone series.

J. H., C. T. C.

* "On the Lamellibranch and Gasteropod Fauna found in the Millstone Grit of Scotland," *Trans. Roy. Soc. Edin.*, vol. xlvi. p. 331.

† *Trans. Roy. Soc. Edin.*, 1905, vol. xli. p. 359.

‡ *Ibid.*, 1906, vol. xlv. p. 134.

§ *Trans. Edin. Geol. Soc.*, 1908, vol. ix. pt. ii. p. 121.

CHAPTER VII.

CALCIFEROUS SANDSTONE SERIES OF THE EDINBURGH, GRANTON AND COLINTON DISTRICT.

This district comprises the city of Edinburgh and Leith, and the tract of country extending westwards along the shore of the Firth of Forth to the mouth of the river Almond, and southwards to the village of Currie on the Water of Leith. It presents a sequence of strata from the base of the Cementstone group to the top of the Hailes sandstone (Fig. 2) together with the important series of volcanic rocks of Arthur's Seat, Calton Hill and Craiglockhart.

The discovery of fish remains of Upper Old Red Sandstone age in the sandstones of Craigmillar and beneath Salisbury Craigs, to which reference has already been made, necessitated the adoption of a new base line for the Carboniferous system in the Edinburgh district. The boundary line has now been drawn where the Ballagan type of the Cementstone group first appears at the top of the red and grey sandstones with cornstones.

Cementstone Group.

The sediments belonging to this group form an important feature in the geology of Edinburgh. The evidence shows that they underlie and are interstratified with the volcanic series of Arthur's Seat and that they follow in normal sequence the lavas and tuffs of Calton Hill. Hence the extrusion of these igneous materials is merely an episode in the history of the Cementstones of Ballagan type as first pointed out by Mr. Goodchild.* They occupy an irregular area in the Old Town between the Castle Rock and Holyrood on the north, and Newington and the Meadows on the south. They are truncated on the north by the Calton fault that runs east and west along the valley of the North British railway, and on the west by the Colinton fault, which traverses the western flanks of Warklaw Hill, Craiglockhart ridge, the Castle Rock and Calton Hill. From time to time they have been laid bare in numerous excavations, in which the strata were found to consist of grey, green, and red mudstones and shales, with cementstone bands, occasional sandstones, and rarely thin dark carbonaceous seams with fossils.

Within this area the strata are arranged in the form of an arch, whose axis runs from the western end of the Meadows towards the Castle Rock. As this anticline is truncated on the west by the Colinton fault just referred to, the complete sequence can be traced only on the eastern limb of the fold, and especially between the Castle Rock and Arthur's Seat (Fig. 3).

* *Trans. Edin. Geol. Soc.*, vol. vii. p. 263.

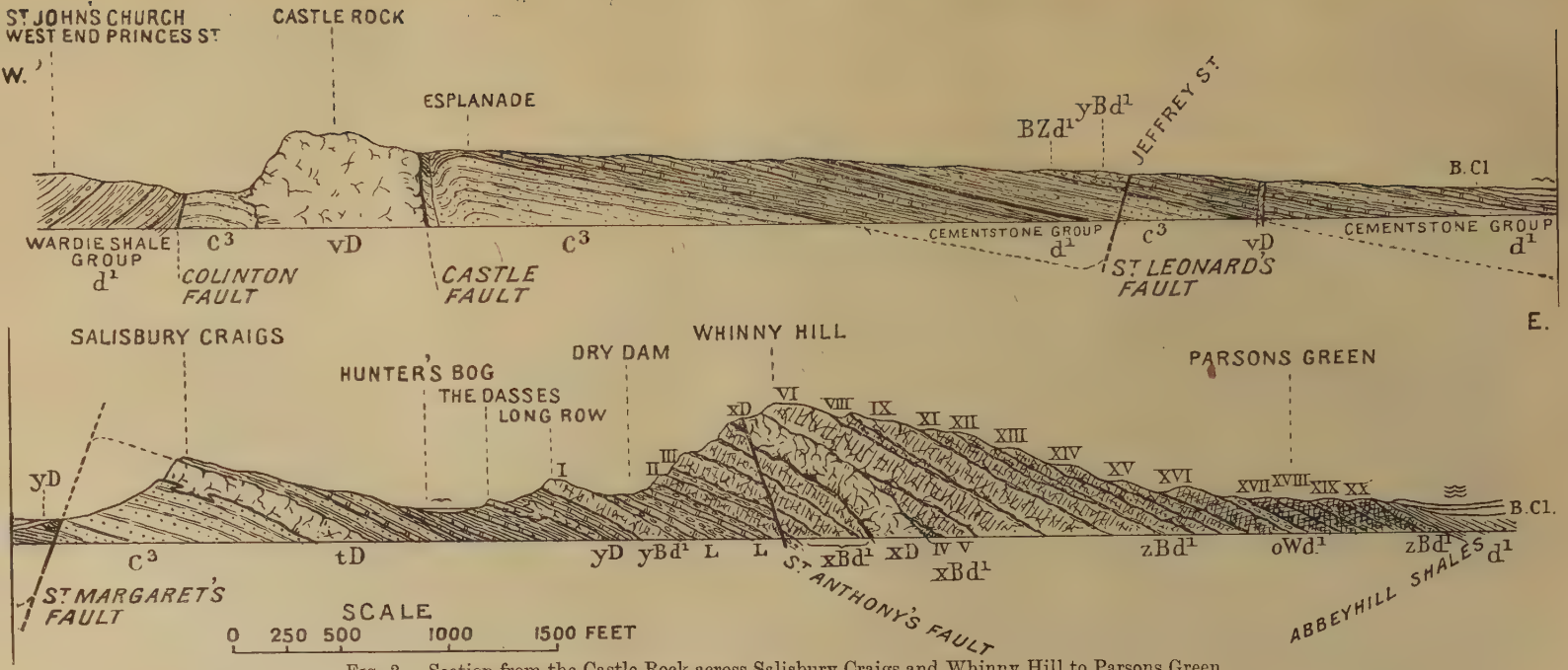

FIG. 3.—Section from the Castle Rock across Salisbury Craigs and Whinny Hill to Parsons Green.

≈ Alluvium. ≋ Raised Beach. B.Cl. Boulder clay. d¹, Calciferous Sandstone series. L. Limestone in d¹. c³, Up. Old Red Sandstone. oWd¹, Mugearite lava. xBd¹, Basalt lava of Craiglockhart type. yBd¹, Basalt lava of Dunsapie type. zBd¹, Basalt lava of Markle type. BZd¹, Basaltic tuffs. tD, Intrusive teschenite. vD, Intrus. basalt of Dalmeny type. xD, Intrus. basalt of Craiglockhart type. yD, Intrus. basalt of Lion's Haunch type. I–XX Lava flows, see page 59 for description and Map at end of volume.

Below the Castle Esplanade, on the slope facing Johnstone Terrace, the highest members of the Upper Old Red Sandstone, consisting of variegated sandstones, with fragments of cornstone, and red and green marls, are exposed. No organic remains have been found in these sandstones. This correlation is based solely on their lithological resemblance to the sandstones beneath Salisbury Craigs and at Craigmillar, which, as already indicated, have yielded fish remains characteristic of this formation. These sediments pass beneath the basal beds of the Cementstone group, which, along the High Street, have a general dip towards the E.N.E., at angles varying from 10° to 15°. Thin basaltic tuffs (BZd^1, Fig. 3) and a basaltic lava of Dunsapie type (yBd^1, Fig. 3) have been recorded near the head of Jeffrey Street, where they are interstratified with the cementstones.

Perhaps the most notable section in this part of the Old Town was that exposed in the course of the excavations for the new offices of *The Scotsman* newspaper, where upwards of 120 ft. of strata were laid bare.* Special interest attaches to this section from the occurrence in it of a band of dark carbonaceous shale, which yielded plants, ostracods and fish remains. The recognisable fragments of plants, determined by Dr. Kidston, comprise *Adiantites lindsæformis* (now known as *Rachopteris inequilatera*), *Stigmaria* and various fern stems. The worms are represented by *Spirorbis carbonarius* and *S. helicteres*, still attached to some of the plant remains. The ostracods, named by Mr. Kirkby, include *Leperditia subrecta*, *L. okeni*, *L. wrightiana* (?), *Kirkbya spiralis* (abundant), *Argillœcia æqualis*, *Aglaia cypridiniformis* (?), *Bythocypris sublunata* (?). The higher crustacea are represented by the portion of a carapace of *Tealliocaris* [*Anthrapalœmon*], while fragments of scorpion skin show the presence of Arachnids. The fishes, determined by Dr. Traquair, are represented by scales of *Rhizodus* and of a palæoniscid fish.†

In a brief descriptive note on the Ostracoda from this section, Mr. Kirkby remarks that all the ostracods are marine forms, with occasional estuarine habits in the case of some of them. Judging from their vertical distribution in other districts than Mid-Lothian, he suggests that the position of the strata in which they occur is in the lower half of the Cementstone group of the Calciferous Sandstone, and probably on the horizon of the Randerstone or Billow Ness beds.‡

At the base of the steep declivity beneath Salisbury Craigs, the cementstones are abruptly truncated by a fault with a downthrow to the west, which brings them in contact with the Upper Old Red Sandstone (Fig. 3). Beyond the dolerite sill of Salisbury Craigs (Plate III.), which seems to have been intruded along or near the boundary line between the Upper Old Red and Carboniferous formations, the shales, cementstones and sandstones of Ballagan type again appear and occupy the hollow known as the Hunter's Bog (Fig. 3 and Map at end of volume). In the Camstone Quarry, near the base of the series, some beds of cementstone are charged with *Estheria peachi*, a small bivalve phyllopod crustacean, which has been found by Mr. Macconochie in the Cementstone group of East Lothian in association with well-known Carboniferous forms.

* *Trans. Edin. Geol. Soc.*, vol. viii. p. 5.
† "Summary of Progress," *Mem. Geol. Sur.* for 1898, p. 131.
‡ *Trans. Edin. Geol. Soc.*, vol. viii. p. 15.

INTRUSIVE SHEET OF TESCHENITE, WITH UPPER OLD RED SANDSTONE IN THE FOREGROUND, SALISBURY CRAIGS, ARTHUR'S SEAT, EDINBURGH.

The total thickness of strata belonging to the lower portion of the Cementstone group in the Hunter's Bog is about 600 ft. Above this horizon the deposition of sediment was interrupted by the extrusion of the volcanic succession of Arthur's Seat which now falls to be described. B. N. P., J. H.

VOLCANIC ROCKS OF ARTHUR'S SEAT.

After a long period of quiescence volcanic energy again manifested itself, early in Carboniferous time, in the Edinburgh region where at least two important volcanoes, namely, those of Arthur's Seat and Corston Hill, for a time discharged lavas and tuffs upon the floor of the lagoon on which the sediments of the Cementstone group were laid down. From time to time subsidiary orifices were opened, such as that which must have supplied the Craiglockhart ashes and lava, while possibly another is represented by the Castle Rock of Edinburgh. A general characteristic of these early eruptions of the Calciferous Sandstone period in Mid-Lothian and other parts of Scotland is the wide distribution of extremely porphyritic basaltic lavas, usually in association with others of the mugearite type.

In Arthur's Seat, at least two separate vents are to be found, the larger of which is of a composite character, showing a slight displacement of the focus of eruption during the life of the volcano. Perhaps the most interesting feature in the history of this volcano is the evidence of the gradual infilling of the central crater by ashes and lavas, while the intercalation of sediment at various horizons clearly shows that the waters of the lagoon from time to time gained access to the crater. Another feature is the intermittent recurrence of the same type of igneous products; thus the Long Row, representing the earliest volcanic extrusion of the hill, is of the same type as the basalt of the Lion's Haunch, which is the youngest product of the volcano that has been preserved. Intermediate in age between these two, lies a varied series of agglomerates and lavas, belonging to at least three distinct types.

The geological structure of Arthur's Seat has long been a fascinating subject of inquiry among geologists. In 1839 Maclaren published the results of his detailed examination of the rocks of the hill,* which showed his comprehensive grasp of the volcanic history of this area and laid the foundation of all subsequent research regarding it. Many of his conclusions have been confirmed by later investigators: one, however, has been disputed, namely, that the volcanic materials belong to two distinct periods of eruption, separated by a vast interval of time. In proof of the latter view he maintained, that the mass of agglomerate which forms the central portion of the hill is merely a cake resting unconformably on an irregular land surface carved out of the older lavas. He regarded the basalt of the Lion's Head as a plug filling up the vent which supplied the later agglomerate. In short, he believed that between the two periods of igneous activity an interval of time elapsed during which the older volcanic series and associated sediments had been folded and subjected to prolonged denudation. In the second edition of his work, published

* "Sketch of the Geology of Fife and the Lothians," 1839, 1st ed. pp. 1–49.

in 1866, Maclaren stated in a note that he had abandoned the view of two periods of eruption.[1]

Arthur's Seat was first mapped on behalf of the Geological Survey by Sir Archibald Geikie, who confirmed Maclaren's observations and accepted his original interpretation. Following a suggestion made by Edward Forbes he considered that the unconformable newer group might be of Tertiary age,* but at a later date he regarded them as more probably connected with the volcanic rocks associated with the sandstones of Permian age in Ayrshire and Dumfriesshire.† His detailed mapping of the Edinburgh district led to the conclusion that the volcanic series of Calton Hill is merely a faulted portion of the Whinny Hill sequence, and therefore included in the basement portion of the Calciferous Sandstone series.

In 1875 Professor Judd published an important paper bearing on the structure of Arthur's Seat, wherein he advocated the theory that the central agglomerates and their associated igneous rocks were contained within a vent from which the bedded lavas and ashes had been erupted.‡

The evidence obtained during the recent revision of Arthur's Seat by the Geological Survey has confirmed Professor Judd's contention and at the same time has shown the accuracy of much of the detailed work of Maclaren and Sir A. Geikie.

The Volcanic Succession outside the Vents.—On the declivity east of Hunter's Bog, the cementstones pass underneath the lowest of the contemporaneous volcanic rocks of the hill, which is represented by the basalt lava of the Long Row (I in Fig. 3 and in Map). It not only caps the ridge between the Hunter's Bog and the Dry Dam and is continued to the north of St. Anthony's fault in the crag of Haggis Knowe, but it also appears to the south of the neck, where it gives rise to the escarpment of the Loch Craig, as was recognised at a very early date by Ami Boué§ (see Map at end of volume). Consisting of dark porphyritic basalt of the Dunsapie (Lion's Haunch) type, but with less conspicuous phenocrysts than the typical rocks, it is slaggy towards the top and bottom, but markedly columnar in its central portion. The manner in which the overlying fine ashy sediments descend into the irregularities of the slaggy upper surface of the basalt seems to demonstrate that it is a true lava flow. This feature may be conveniently studied in the road section in the Queen's Drive above the Loch Craig. In places the ashes that fill up the fissured and uneven surface of the basalt are slightly indurated, thus indicating that the lava must have retained a considerable amount of residual heat when the tuffs were deposited.

The basalt of the Long Row is followed to the east of the Dry Dam by about 100 ft. of strata, consisting chiefly of well-bedded basic tuff with numerous sedimentary intercalations, mostly calcareous. Near St. Anthony's Well two calcareous bands are specially conspicuous, one near the base and the other near the top of the tuff (L, Fig. 3). The lower one, exposed beside the small reservoir that

[1] "Sketch of the Geology of Fife and the Lothians," 1866, 2nd ed. p. 47.
* "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861, p. 123.
† "Ancient Volcanoes of Great Britain," vol. ii. p. 68.
‡ *Quart. Jour. Geol. Soc.*, vol. xxxi. p. 131.
§ *Essai géologique sur l'Ecosse* (Paris, 1820), p. 196.

supplies the well, is about three feet thick, and is siliceous, and concretionary. It is associated with dark sandy shale full of plant remains. From these beds the late Mr. David Grieve obtained the fossils mentioned by Dr. Traquair.* Plant remains are also found in the ashy beds overlying the limestone. In the path leading up to St. Anthony's Chapel concretionary white limestones occur interbedded with the ash, and these are traversed by rootlets of plants which must have grown *in situ*. The band of limestone near the top of the tuff is to be seen a little farther up the hill slope, and also contains roots or stems of plants in which the structure is preserved. The highest beds visible in this section consist of grey flaggy calcareous sandstone with an occasional admixture of ashy material.

South of the vents this group of ashes is exposed above the Loch Craig, where the Long Row basalt crosses the Queen's Drive. Here they consist of fine-grained reddish tuff and ashy sandstones. After a space concealed by turf, which must represent nearly 100 ft. of similar strata as shown by their debris, a white limestone like that seen at St. Anthony's Well protrudes through the turf and dips steeply towards the east (see Map). A similar section is exposed eastwards from the foot of the Loch Craig on the Duddingston Road, where the ashy sandstones contain concretionary calcareous nodules. Up to this point the sequence found on both sides of the vents is in very close agreement, but above this horizon there is a marked variation. In order that this variation may be clearly realised, the succession, occurring to the north and south of the vents, is presented below in descending order—

WHINNY HILL SEQUENCE (NORTH OF THE VENTS).	DUDDINGSTON SEQUENCE (SOUTH OF THE VENTS).
No. XX lava. A basalt of Markle type.	The upper ash or agglomerate of Duddingston containing abundant blocks of Markle type. Two basalt flows of Markle type also occur here, well up in the agglomerate, and the latter passes under a group of lavas (Markle basalt and a mugearite) exposed on the slopes of Dunsapie. The mugearite flow, the highest rock visible, is probably of earlier date than the mugearites of the Parson's Green, and the section becomes obscured by drift at a much lower level on this side than to the north.
Nos. XVI–XIX lavas. The Parson's Green group of Mugearites with thin ashes.	
Nos. VII–XV lavas. Basalt flows of Markle type with thin ashes.	
Nos. III–VI lavas. Basalt flows of Craiglockhart type, but rarely conspicuously porphyritic.	
Upper Ash of Dry Dam containing no fragments of Markle type.	
No. II lava. Craiglockhart type, but not conspicuously porphyritic.	
Lower Ash of Dry Dam containing no fragments of Markle type.	Lower Ash of Duddingston containing no fragments of Markle type.
No. I lava. The Long Row basalt of Dunsapie type.	Loch Craig basalt.

The asymmetrical development of the volcanic series, indicated by the two sections in the above table, suggests that the vent may have been active at the beginning of the volcanic history of this area. In confirmation of this view it may here be stated, that the existence of an early formed central cinder cone is indicated by the behaviour of the second ash in the Dry Dam, while the neck itself can be divided into an older portion free from blocks of the Markle

* *Trans. Roy. Soc. Edin.*, 1903, vol. xl. p. 689.

type of basalt, and a later portion in which they occur. These points will be dealt with in the sequel.

Succession above the Lower Tuff of the Dry Dam North of the Vents.—The lower ash and sediments of the Dry Dam are overlain by a second flow of basalt (No. II in Fig. 3, and in Map), which can be best studied in the small crag underneath St. Anthony's Chapel on the north side of St. Anthony's fault. The rock resembles the Craiglockhart type, but with the olivine and augite less conspicuously porphyritic and greatly decomposed. The flow is slaggy throughout, and has an extremely irregular upper surface, the depressions and cracks of which are filled in with fine tuff and bedded limestone. South of St. Anthony's fault, the outcrop of this lava is interrupted for a short distance by a basaltic intrusion of the same type as the flow; it is, however, markedly columnar and makes a conspicuous feature on the north side of the Dry Dam. Beyond this intrusion the lava with its characteristic features can be followed to the head of the Dry Dam.

In the section exposed in the small crag under St. Anthony's Chapel the ash filling in the cracks of No. II lava can be traced upwards into a continuous band of well-bedded tuff with occasional large bomb-like masses of basalt, some nearly a foot across. The ash is here about four feet thick, and a thin layer near its top is nearly black owing to the presence of carbonaceous matter, and is hardened by infiltration of iron. This bed has been referred to by Dr. Traquair as having yielded to Dr. MacBain * a tooth of *Rhizodus*. Fragments of *Calamites*, *Stigmaria*, and the remains of *Elonichthys striatus*, *Callopristodus pectinatus* (determined by Dr. Traquair) were obtained by the Geological Survey from this band of tuff. The ashes at this point have been plicated by the drag of the succeeding lava flow, the overfolding indicating that the lava moved in a northerly direction over beds still in a soft and pliable condition.

South of St. Anthony's fault the tuff can be followed continuously to the edge of the vent, rapidly increasing in thickness and in the coarseness of its materials (see Map). Only fragments of basalt of the type of the underlying lavas have been obtained in this deposit.

Next in order at St. Anthony's Chapel comes the third lava (III in Fig. 3 and in Map), forming the crag on which the ruin stands. It is petrographically similar to No. II, but with a compact central portion slightly vesicular and remarkably columnar in structure. Its upper part near St. Anthony's Chapel is much brecciated, as if by explosive emission of gases. South of the fault where it gives rise to a continuous crag, it is rendered conspicuous by its columnar central portion with its orange-coloured incrustation. The dark slaggy upper part of the flow here also attracts attention owing to the masses of bedded limestone with which its cavernous spaces have been filled.

Similar features are illustrated in the succeeding lava flow (IV in Fig. 3 and in Map), which is traceable on both sides of St. Anthony's fault, on the one side as far as the central vent, and on the other to the crag overhanging St. Anthony's Chapel. An interesting feature may be noticed where the upper portion of

* *Trans. Roy. Soc. Edin.*, vol. xl. p. 689.

this flow forms the crest of the ridge, to the south of the fault. At this point a clearly defined layer can be recognised by the large size of its porphyritic constituents. Although the line of demarcation between the two types of rock can be readily traced, the passage is not abrupt and is parallel with the flow banding of the underlying finer-grained rock, showing that differentiation had occurred within the magma, at least as regards the formation of the phenocrysts before the flow had ceased, and probably before the lava had been extruded.

The fifth flow is a basalt of the same type as No. IV, and illustrates most of the features just described. In a small escarpment near its southern extremity, its weathered columnar central portion recalls the appearance of the columns in the celebrated Cheese Grotto at Bertrich in the Eifel. Along the southern half of its outcrop the fifth lava flow is succeeded by a sheet of basalt of doubtful relationship. It is a coarsely porphyritic rock of normal Craiglockhart type, resembling the upper portion of the fourth flow. The characteristic slaggy character is, however, absent at the top and bottom of this sheet, and its thickness is great compared with its lateral extent, so that it differs widely from the undoubted flows with which it is associated. This evidence therefore favours the view adopted tentatively in the mapping that this rock is an intrusive mass.

The lava next in order (No. VI in Fig. 3 and in Map) is traceable from side to side of the Whinny Hill, is of considerable thickness, and repeats some of the features presented by the fourth and fifth flows. It is the last of the group of finely porphyritic lavas of the Craiglockhart type which began with No. II flow in Arthur's Seat.

The seventh lava flow is only known at the north end of the hill where it extends upwards for a few hundred yards from the bend of the Queen's Drive east of St. Margaret's Loch. It is the first of a group of basalt flows with conspicuous phenocrysts of labradorite (Markle type), which were mapped by Sir Archibald Geikie under the name of "Porphyrite."

The overlying group, comprising eight flows (Nos. VIII–XV in Fig. 3 and in Map), form the main part of the Whinny Hill, the outcrops of most of which extend right across the hill. Although there is no important bed of ash in the series, the slaggy surfaces of the different flows are usually separated from each other by tuff, which helps to set forth the bedded character of the volcanic materials. Columnar structure is not a marked characteristic of the lavas of this group, indeed they are more or less vesicular throughout with very irregular upper surfaces. The last feature is well illustrated on the east face of the hill about half-way between Dunsapie Loch and Parson's Green, where the top of No. XII lava flow is exposed in a small scar facing the north. The upper two or three feet are seen to be composed of a rough heap of slaggy clinkers, many of which, in the arrangement of their phenocrysts and their vesicles, show a rude flow structure conforming more or less to the outlines of the separate masses. This is not an agglomerate resting on the top of the lava but is an integral part of the latter, as can be clearly seen in the section. Between these clinkers and reaching down into the more solid portions of the flow there extends a red

ashy sandstone constantly showing traces of bedding, which, in the larger cavities, is inclined in the general direction of the bedding planes of the rocks of the hill. The relations of the tuff to the uneven surface are also exhibited on the exposed dip slope of the lava, where wisps of slaggy basalt protrude in places through the covering of ash. The most important of these bands of tuff is to be seen at the side of the Queen's Drive at the north-east corner of the Park, where it separates the fourteenth and fifteenth lava flows.

Next in order come mugearite lavas (XVI–XIX, Fig. 3), probably four in all, which are easily distinguished by their non-porphyritic character, their platy flow structure, and a tendency to assume a rude columnar character. The lowest of these flows (No. XVI) is exposed at the north-east extremity of the park, the boundary wall being built upon the bared upper surface. Although the top is here not particularly vesicular, the lowest portion of the succeeding ash bed is seen to descend into the irregularities of the surface. A section of the upper part of this ash is exposed in Scone Gardens, where it dips to the east at an angle of 20°. The rock is a fine reddish volcanic grit about 20 ft. in thickness, which is succeeded by a lava (No. XVII in Fig. 3 and in Map) that has been recently opened up and quarried for road metal. Probably the same flow is exposed in a cutting at the back of the engine shed of the Locomotive Depôt of the North British Railway not far to the north, where it is succeeded by two bands of mugearite with thin intercalations of tuff. In the last-named section the uppermost of the mugearite lavas is separated by a thin bed of ash from a higher porphyritic flow, thus showing a reversion to the Markle type of lava. This rock, which is fresher than most of those of the Whinny Hill, probably represents the last of the extrusions in the volcanic sequence of Arthur's Seat. The top of this bed is not visible, being covered by a thin coating of drift and by the basement beds of the 100-ft. beach.

None of the lavas or ashes of the Whinny Hill can be traced southwards with certainty beyond the Queen's Drive at the north end of Dunsapie Loch, the relations of the isolated areas of lavas east of Dunsapie to those of Whinny Hill being hidden beneath boulder clay.

Succession above the Lower Tuff of the Dry Dam on the South Side of the Vents towards Duddingston.—The fine tuff associated with the limestone band overlying the lava of the Loch Craig (No. I, Long Row), which has been identified with the lower ash of the Dry Dam, is here succeeded by a mass of coarse well-bedded agglomerate (BZd^1 in Map) dipping to the north of east at the same average angle as the rocks of Whinny Hill. A feature which at once distinguishes this agglomerate from either of those in the Dry Dam is that the larger fragments are mainly composed of the Markle type of basalt with large porphyritic felspars. One of the blocks in this agglomerate measures nine feet across. This mass of pyroclastic material is succeeded by two lava flows of Markle type (zBd^1), which form an escarpment obliquely crossing the slope of the hill below the level of the Queen's Drive. At a somewhat higher horizon finer agglomerate is associated with a band of white limestone, containing black patches

of calcite and chert, which is exposed at intervals in the slope above the road, and is also seen by the Queen's Drive, where it bends to the north to Dunsapie Loch. North of the Duddingston entrance to the park the continuation of the section is concealed by drift.

Dunsapie Crag is composed of intrusive dolerite (YD in Map), which on the east truncates two lava flows dipping towards the east, the lower being a porphyritic basalt of Markle type and the upper a mugearite lava showing the characteristic platy structure. The relations of these isolated exposures to the lavas of Whinny Hill are quite uncertain, but it seems unlikely that this mugearite can be on the same horizon as the flows exposed at the north-east corner of the park. In the latter section the mugearite lavas lie between basaltic flows of Markle type, and it is probable that the Dunsapie mugearite represents a still earlier lava stream which did not reach the Whinny Hill.

Comparison of Sections North and South of Vents.—As already indicated, the lower portion of tuff with the limestone band exposed above the basalt of the Loch Craig on the south side of the vents corresponds in position and lithological characters with the ashes and sediments of the Dry Dam. Above the first 150 ft. the correspondence ceases. No lavas of Craiglockhart type occur on the south side of the vents, and the succeeding flows of Markle type, so conspicuous in the Whinny Hill, are represented to the south by agglomerates made up in part of this type of basalt with only subordinate outpourings of lava. The present configuration of the larger vent is of later date than the formation of the whole of the lower portion of the volcanic pile, including all the lavas of Craiglockhart type; but the lack of agreement in the details of the section on each side points to the earlier existence of a small orifice occupying part of the site of the larger one. In this connection the rapid thickening of the upper agglomerate of the Dry Dam towards the south becomes very significant. In fact, to judge by the sudden increase in thickness of the band and concurrent increase in the size of its contained blocks, it seems certain that at this point the bed must have once formed portion of a small cinder cone. The limited distribution of the lava flows of Craiglockhart type can readily be accounted for by supposing that the uprising lavas breached the cinder cone at some point on its northern side. Similar considerations might also account for the predominance of agglomerate to the south and of lavas to the north, when, at a slightly later date, the volcano was producing the basalts of the Markle type in association with mugearites. As might be expected, the Calton Hill section, to be described later, combines many of the features which distinguish the two sides of the vent in the present area.

The Vents of Arthur's Seat.—A glance at the Map shows that the boundary of the materials constituting the central part of the hill is a line of very marked discordance. To the north-west of Samson's Ribs it truncates the Upper Old Red Sandstone, and when traced eastwards to Dunsapie Loch it traverses the outcrop of the cementstones and a large portion of the volcanic series. Either the agglomerate which makes up the greater part of the material inside the line is lying as an

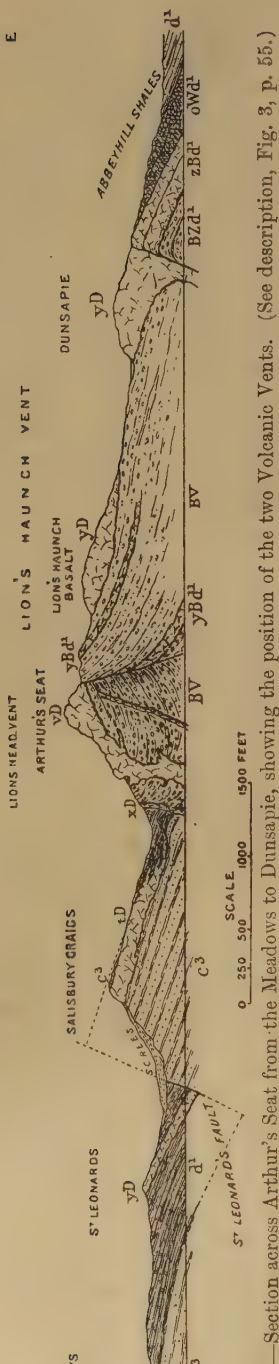

FIG. 4.—Section across Arthur's Seat from the Meadows to Dunsapie, showing the position of the two Volcanic Vents. (See description, Fig. 3, p. 55.)

unconformable cake upon the denuded edges of the surrounding rocks as Maclaren originally supposed, or it rises steeply through these rocks, and fills a vent as advocated by Professor Judd. The main line of argument adopted by Professor Judd depends upon the close resemblance between the products of what had been previously supposed to belong to quite distinct periods of eruption. With increasing petrographical knowledge, the importance to be attached to evidence of this nature has become more apparent. In the case of the blocks contained in the agglomerate and the intrusions by which it is injected, the records of Scottish vulcanicity point to the conclusion that they could not have been produced except during the Calciferous Sandstone period. On this ground alone any hypothesis based on unconformability is extremely improbable, and this conclusion is strengthened by the field evidence in support of the opposite view, which now falls to be described.

As shown on the Map, the area occupied by the discordant material includes the central eminence of Arthur's Seat and extends east to Dunsapie. It can be subdivided into two unequal portions representing separate vents, the boundary between them being marked by a line drawn approximately from the north end of the Raven's Rock to the head of the Dry Dam (Fig. 4 and Map at end of volume). The smaller orifice to the north-west of this line, including the summit of Arthur's Seat, may be termed the Lion's Head vent, and the larger one to the south-east the Lion's Haunch vent (Plate I.).

The Lion's Head Vent.—In this orifice there is everywhere a well-marked concentric arrangement of the constituents of the agglomerate with steep inward dip, while the upper part of the basalt intrusion of the Lion's Head rests in a cup-shaped depression, conforming more or less to the bedding of the agglomerate (Fig. 4). The stratification of the agglomerate is indicated by the alternation of coarser and finer layers. The

included blocks consist almost wholly of basalt of Craiglockhart and Dunsapie types, which impart a greenish tinge to the rock except where it is locally stained red. No fragments of the highly porphyritic Markle basalts have been detected here, though they are common in the agglomerate of the Lion's Haunch vent. Another characteristic is the relatively finer texture of the agglomerate in the smaller neck. It is probable that the Lion's Head orifice was active only during the earlier stages of the history of the volcano, that is, before the extrusion of the greater part of the Whinny Hill lavas.

The boundary of the Lion's Head vent is clearly indicated along its northern margin where it truncates the cementstones forming the eastern slopes of the Hunter's Bog and the lava flow of the Long Row. Thence it runs east and west at right angles to the strike of the adjoining lavas and ashes. A thin dyke of brecciated basalt has been injected along the line of junction and can be followed for about fifty yards. The basalt of the Long Row, when it approaches the margin of the vent, shows signs of great disturbance and shattering, but the actual junction is concealed under surface débris. A little farther down the slope, bands of altered cementstone are found in contact with the dyke, and are bent down towards the junction. Inside this intrusion the ash of the neck can be seen to dip away from the dyke at angles of 45° to 50° and to be stepped down by numerous small faults (see Map at end of volume.)

The western boundary is entirely concealed under talus. The nature of the junction line on the south-east side is indicated by the exposure at its south-west limit where the relation of the agglomerates of the Lion's Haunch to those of the Lion's Head vent can be seen in clear section in the gully known as the "Gutted Haddie" descending the western front of the hill (see Map at end of volume). The line is evidently that of a neck junction, and there is a marked discordance between the materials filling up the two orifices. The comparatively fine agglomerates dipping north-east under the basalt capping of the Lion's Head are abruptly truncated against a highly inclined plane along which there are obvious signs of movement (Fig. 4). On the other side of the plane lies the coarse red agglomerate characteristic of the Lion's Haunch, distinguished from that just described by the presence of fragments of the Markle type of basalt. This deposit is also bedded and dips at an extremely high angle towards the south-east (see Map at end of volume). That this inclination is due to central subsidence rather than to deposition at the angle of repose of the material is shown by the presence of a bed of sandstone, greatly crushed but traceable for some distance and conforming with the high inclination of the agglomerates. Far down the section, beds occur rich in fragments of a basalt resembling that of the Lion's Head, and at the very top of the "Gutted Haddie" a breccia occurs in contact with this basalt and entirely made up of its fragments although lying to the east of the division line between the two agglomerates (see Map). This breccia is affected by lines of crush, nevertheless it has the appearance of an original scree formation, and, what is particularly significant, it passes laterally into the normal agglomerates of the Lion's Haunch.

These phenomena seem to point to the existence of two vents, that of the Lion's Head and that of the Lion's Haunch. The latter came into operation at a slightly later date than the former, and was drilled partly alongside and partly within the limits of the original orifice. The constituents of the older neck, including the intrusion of the Lion's Head, actually formed part of the boundary wall of the new vent and supplied screes which mingled with the exploded material. Thus it appears that the basalt of the Lion's Head, although the youngest rock of the older vent, really belongs to the early suite of eruptions that produced the agglomerate with which it is so intimately associated. The rock is a fine-grained basalt of the Dalmeny type identical with that of the Castle Rock of Edinburgh to be described in the sequel, and closely related to the Craiglockhart type of basalt of the lower part of the Whinny Hill.

On the west side of the hill, in the cliffs just above the footpath that traverses the talus, the roots of the Lion's Head intrusion are exposed as a series of ramifying dykes, uniting upwards to form a stem which passes nearly vertically through the agglomerate for about 175 ft., and finally spreads out more or less parallel with the bedding planes of the agglomerate (Fig. 4). A marked flow structure is visible, which everywhere follows the marginal limits of the rock, while at the same time there is a rude columnar structure at right angles to the fluxion lines. Two additional exposures of basalt occur within the Lion's Head orifice, the chief one being a small dyke from two to three feet across, that rises vertically through the bedded agglomerate a little to the north of the "Gutted Haddie" gully. It is a porphyritic basalt different from that of the Lion's Head. The margins of the dykes show a platy fluxion structure and the centre is highly vesicular and amygdaloidal.

Lion's Haunch Vent.—The materials filling up the Lion's Haunch orifice are more varied than those in the smaller vent just described. While agglomerate predominates, there are also undoubted lava flows at three different levels, together with sandstones, marls and cementstones. Massive intrusions also occur within the vent.

The section exposed on either side of the Queen's Drive, from Powderhouse Corner to the escarpment of the Loch Craig, furnishes evidence regarding the complex nature and arrangement of the materials inside the vent, and also of their relations to the bedded rocks outside the limits of the orifice (see Map at end of volume). The Raven's Rock above the road at Powderhouse Corner forms part of a crag that runs south from the gully of the "Gutted Haddie" to the west end of Samson's Ribs and consists of a series of slaggy porphyritic basalt lavas of Dunsapie type, associated with breccias, ashes, and occasional beds of red marly tuff. The manner in which the finer tuffs and sediments fill the uneven surfaces of the slaggy lavas leaves no doubt as to the superficial origin of the latter, while the occurrence of such deposits with their even bedding planes indicates that at the time of their formation they must have been nearly horizontal and continuous, though now either vertical or highly inclined towards the east. Hence there is here evidence of the central subsidence having affected the materials of the Lion's Haunch Neck. In this section the rocks are traversed by several veins of intrusive basalt resembling the lavas themselves, but it

COLUMNAR BASALT WITHIN THE LION'S HAUNCH VENT, SAMSON'S RIBS, ARTHUR'S SEAT.

is uncertain whether they have emanated from the main mass of Samson's Ribs or are more directly connected with the production of the lava flows. Where this group crosses the road at the first bend, their strike is deflected to the south-east so as to run almost parallel with the road and also with the boundary of the vent, the dip being north-easterly at high angles. Here the intrusive basalt of Samson's Ribs splits up the group, and part of the breccias belonging to it flanks the western side of this intrusion as far down as the Duddingston Road, where the line between the two rocks is irregular and nearly vertical. The upper portion of the group obviously overlies the basalt of Samson's Ribs and is exposed on both sides of the road. The well-preserved *roche moutonnée* exposed in the Queen's Drive at this point belongs to one of these lava flows.

The massive intrusion of Samson's Ribs, so well known on account of its columnar structure, is a basalt of Dunsapie type (Plate IV.). Viewed from the Duddingston Road the most significant feature is the manner in which the steeply inclined columns bend outwards and become almost horizontal as they approach that road, as if chilled against a nearly vertical face. Indeed, the basalt of Samson's Ribs appears to have welled up along the margin of the vent and to have extended laterally chiefly among the lavas and breccias of the group just described. It must have been injected after the extrusion of the latter as it sends an important tongue into the overlying red agglomerate which now falls to be described. This tongue is well seen above the Queen's Drive and makes a conspicuous feature owing to the slight radiation of the fine columns.

The junction of the red agglomerate with the uppermost member of the underlying volcanic group within the vent can readily be traced from the "Gutted Haddie" above the Raven's Rock to the Queen's Drive. The agglomerate is well bedded even in its coarsest form, the stratification being indicated by the arrangement of the large blocks, which consist chiefly of basalt of Dunsapie or Lion's Haunch type together with fragments of the Markle type of basalt, the latter being readily recognised by the abundant phenocrysts of felspar. At irregular intervals there are intercalations of fine ash and even of quartzose and calcareous sedimentary materials.

In the first cliff exposed above the road after passing the tongue of columnar basalt proceeding from the intrusion of Samson's Ribs there is a considerable thickness of these coarse agglomerates with a steep dip towards the north-east. About 30 yds. east from the beginning of the cliff, a few feet of ashy sandstone and cementstone are overlain by a slaggy and often brecciated basalt lava of Dunsapie type. The irregular slaggy top of the flow with its cracks and hollows filled in with tuff is repeated by a fault oblique to the Queen's Drive, and a continuation of the lava is also seen a little below the road. For the next 70 yds. very coarse agglomerate with finer intercalations occupies the cliff with the same high inclination towards the north-east. At this point a mass of porphyritic basalt, several square yards in extent, is seen to be cut off to the east by a nearly vertical bed of fine red agglomerate. The mass is like a dyke intrusion, but is more probably only a very large block in the agglomerate which is extremely coarse at this point and filled with fragments of similar basalt.

The fine red agglomerate is followed by a slaggy lava flow of Dunsapie type, showing signs of flow-brecciation, which appears in the section for the next 100 yds. The very irregular surface of the lava is overlain by a few feet of red ashy marls with sandstone and cementstone bands which descend into the crevices of the slaggy surface. Here again the nature of these bedded sediments, which much resemble many of the rocks of the Cementstone group found outside the vent, precludes the hypothesis that they could have been formed at the angle at which they now lie, and it is certain that the continuation of the outcrop of this lava flow in the road section with an average E.N.E. and W.S.W. strike has been determined by central subsidence. The same deflection of the strike is observable in the agglomerates which overlie this lava at a point near where the road section is hidden by the retaining wall.

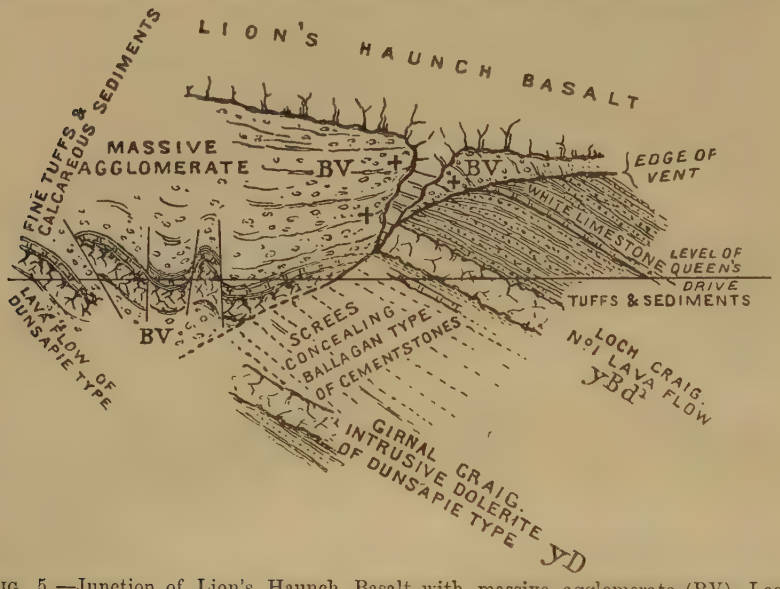

Fig. 5.—Junction of Lion's Haunch Basalt with massive agglomerate (BV), Loch Craig lava (yBd^1), tuffs, and sediments in Queen's Drive. Fragments of white limestone in agglomerate (+ +). Horizontal distance about 1000 ft.

These phenomena, indicating central subsidence and drag against the vent wall, are supported by the evidence of disturbance such as faulting, slickensiding and shattering, that is everywhere apparent in these rocks.

In the concealed ground the marginal line must cross the road obliquely since an outcrop of the sandstones and cementstones underlying the intrusion of the Girnal Craig with a N.W. and S.E. strike can be traced to within 70 ft. of the road section just described. The edge of the vent can be seen a little farther up the hill in the section rendered classic by the descriptions of Maclaren, Geikie and Judd (Fig. 5). The exposures here are far from perfect and the nature of the junction has for the most part to be inferred from the relation of isolated outcrops. There can be no doubt, however, that a line running obliquely up the hill in a north-east direction separates two distinct groups of rocks. On the north-west side of this

boundary the agglomerates of the road section continue for a space dipping towards the north-west at low angles. At this point they are characterised not only by the abundance of blocks of the Markle type of basalt, but also by the presence of many large fragments of fine-bedded ashy sandstone, and pieces of limestone similar to the deposits occurring above the Long Row basalt on both sides of the hill. These are interrupted by a tongue of basalt connected with the intrusion of the Lion's Haunch (Fig. 5), beyond which a crag of agglomerate resembling that just described projects through the turf, but with a south-east dip. On the south-east side of the line the basalt of the Loch Craig is well exposed and is followed, at the Queen's Drive, by the characteristic ashy sandstones with a north-east dip, while, up the hillside, a prominent rib of white limestone or cementstone (Fig. 5), similar to that occurring in the Dry Dam near St. Anthony's Chapel, can be traced to within a few yards of the projecting crag of agglomerate already mentioned. Its outcrop then ceases, and although the section is much grassed over it is highly probable that the limestone does not continue farther in this direction. The principal feature of the section is the very obvious truncation of the Loch Craig (Long Row) basalt by the agglomerate (Fig. 5), for although the tongue of Lion's Haunch basalt intervenes at one point it does not affect the relationship of the other two rocks.

Apart from its bearing upon the questions discussed, the contact of the basalt of the Loch Craig with that of the Lion's Haunch is of great interest. Both Sir Archibald Geikie and Professor Judd are agreed that the tongue is intrusive against the older lava, and according to either interpretation a certain lapse of time must have intervened between the production of the two rocks of similar petrological character. Since it has now been shown that basalts of the Markle type and also mugearites are abundantly represented in the agglomerate into which the Lion's Haunch rock is intruded, it is clear that the eruption of the Lion's Haunch basalt marked a reversion to the earliest type of lava represented in the hill after the volcano had passed through a highly complicated development. While the recurrent phase is demonstrated in this particular section by the actual conjunction of the newer and older products, it is equally illustrated by the relations of the Dunsapie mass and other intrusions and lava flows within the neck to the agglomerate with which they are associated, and in some cases also to the lavas outside the vent. The characters which distinguish the Lion's Haunch rock from the contiguous lava are its more coarsely porphyritic texture, its greater freshness, its comparative freedom from vesicular structure, its more jointed appearance and its reddish weathering. By these means it is possible to distinguish the junction line of the two rocks.

Eastwards from the section just described the position of the boundary line of the vent is quite uncertain. The existence of the neck in this direction is inferred from exposures on the north side of the orifice to be described in the sequel. Although the available evidence does not favour the view, it is possible that the agglomerate with the limestone containing the dark chert nodules, and also the lava flows of Markle type, described in the section on page 62 as

forming the bedded series on this side of the hill, may really be included within the vent.

At Dunsapie the evidence becomes more definite. The disposition of the columns within the massive intrusion at that locality indicates that it forms part of a sheet inclined towards the north-east; but the intrusive character is shown by the manner in which it truncates the lavas exposed upon the eastern flanks of Dunsapie (Fig. 4). To the west of Dunsapie Loch there is an exposure of a very coarse agglomerate including blocks up to five feet across chiefly of Dunsapie type of basalt, together with fragments of Markle type and mugearite. From this point up to the northern extremity of the Lion's Haunch basalt a series of shallow excavations was made at intervals of a few yards, which indicate that this grassy slope is underlain by coarser and finer agglomerates with similar contents (Fig. 4). In places where the finer agglomerate showed an arrangement of the material, the dip was found to be towards the north-east. The relations of the main mass of the Lion's Haunch intrusion to the agglomerates exposed beneath its western escarpment clearly indicate that it is a superincumbent sheet inclined towards the north-east like the agglomerate (Fig. 4). It has been suggested that the basalt intrusion of Lion's Haunch and Dunsapie may be portions of the same sill, though now cut off from each other by denudation; but Dr. Flett, who has had exceptional opportunities of studying the two rocks microscopically, is of opinion that they present differences which make them readily distinguishable from each other, thus making this hypothesis highly improbable.

It will be observed that in this part of the vent there are few, if any, indications of differential movement due to central subsidence so obvious in the portions hitherto described. All the phenomena connected with the dip of the materials could be fully accounted for by the supposition that here the bedding remained approximately horizontal until the folding of the region as a whole. Such evidence is opposed to the view that the igneous products of Arthur's Seat might belong to two epochs separated from each other by a period of great earth movement accompanied by denudation.

To the north of the agglomerate a triangular area, extending from near Dunsapie Loch to the head of the Dry Dam, is occupied by porphyritic basalt of the Dunsapie type (yBd^1 in Map at end of volume). In some of the exposures the rock is seen to be thoroughly slaggy, and, when viewed in connection with the contour of the ground, it suggests the presence of at least two lava flows. At the col at the head of the Dry Dam two ribs run up the hillside, and it is a remarkable fact that these are in such direct continuation with the escarpment features made by the outcrops of lavas II and III of the Whinny Hill succession, that only by attention to the different petrographical characters of the rocks can one be convinced of the existence of the line of discontinuity in the intervening hollow. This continuity of feature accompanied by the difference of the rocks on each side of the line did not escape the acute observation of Maclaren, who, however, tried to account for the presence of these lava flows by inserting a fault along the line we now take to be the outer edge of the neck. He assumed in fact that the lavas were downthrown portions of some of the porphyritic basalts of the

Whinny Hill. Sir Archibald Geikie found this hypothesis to be untenable and rightly placed these lava-form rocks with the agglomerates of the central part of the hill. It may be pointed out now that microscopic investigation shows that these rocks belong to the Dunsapie type of basalt so well represented in the lavas, agglomerates, and intrusive masses of the vent, and clearly distinguishable from the Markle type of basalt that characterises the lavas of the upper part of the Whinny Hill with which Maclaren originally compared them.

These lava-form rocks probably underlie the agglomerates upon which the Lion's Haunch sill rests, and therefore seem to be in the same stratigraphical position in the vent as the much faulted lava of similar type exposed in the Queen's Drive on the south side of the hill (Fig. 5). Some small isolated exposures of brecciated slaggy basalt of Dunsapie type protrude through the turf in the hollow between the Lion's Head and the Lion's Haunch which also appear to belong to lavas intercalated in the agglomerate about this horizon.

Agglomerate, evidently underlying the lowest of the lava flows within the vent overlooking the Dry Dam, is exposed at the junction of the two paths that lead up to the top of the hill on the north side. The pyroclastic material dips easterly, thus agreeing generally with the inclination of the bedded rocks outside. This exposure must be near the junction of the Lion's Haunch vent with the older orifice to the north, and the next exposures on the hill face clearly belong to the latter.

Vent near Camstone Quarry.—Having described the great central vents of Arthur's Seat, we may now direct attention to a subsidiary vent giving rise to an elongated mound on the dip slope of Salisbury Craigs between the Cat Nick and the Camstone Quarry. Along its major axis, which lies E.N.E. and W.S.W. it measures fully 200 yds. and its breadth is about 70 yds. (see Map at end of volume). At its eastern extremity the agglomerate with which it is entirely filled cuts through the Upper Old Red Sandstone and contains numerous fragments of that material. Elsewhere its junctions are not exposed, but since it lies obliquely to the outcrop of the sandstones its relations, like those of the agglomerates on Arthur's Seat, can only be those of unconformity or intrusion in the form of a vent. Here there is additional evidence to associate this agglomerate with the Carboniferous period since it has been greatly indurated by the dolerite intrusion of Salisbury Craigs which, for reasons to be given in the sequel, is itself probably of Lower Carboniferous age. The included blocks at once recall the lavas of the lower portion of the Whinny Hill, while the Markle type of basalt is absent, so that it may be inferred that its period of activity was restricted, like that of the Lion's Head vent, to the earlier portion of the volcanic history of Arthur's Seat.

INTRUSIVE IGNEOUS ROCKS OF ARTHUR'S SEAT AND CASTLE ROCK.

Reference must now be made to the intrusive rocks occurring in Arthur's Seat, which comprise (1) the sheet of Heriot's Mount and St. Leonard's Craig, (2) the Dasses and the Girnal Craig, (3) the

dolerite sill of Salisbury Craigs and (4) the intrusive mass at Duddingston.

With regard to the rock of the Dasses its intrusive nature was clearly recognised by the early observers. It is a conspicuously porphyritic basalt of Dunsapie type occurring as a thin sheet, overlain by three irregular lenticular masses, which thin out among the surrounding sediments. The latter show obvious signs of having been disturbed and indurated by the molten rock. The occurrence of a sill of the same type and occupying a like stratigraphical position both to the south of the vents (the Girnal Craig), and also in the faulted area to the west of Salisbury Craigs (St. Leonard's Craig), points to a greater extension for this intrusion than might have been expected from the appearances presented by the Dasses themselves.

The correlation of the basalt of Girnal Craig with that of the Dasses was made by Maclaren, who realised its intrusive character and the alteration of the overlying cementstones as seen on the shore of Duddingston Loch. The basalt of St. Leonard's Craig has been linked with that of the Dasses in view of the discovery of Upper Old Red Sandstone fish remains in the sandstones underlying Salisbury Craigs, from which it was inferred that the cementstones into which the St. Leonard's basalt has been intruded belong to the Cementstone group of the Hunter's Bog, repeated by a fault (Fig. 3). Although the basalt sill of the Girnal Craig, as shown on the Map, appears as if truncated by the edge of the vent, the section is obscure at this point, and it is by no means certain that such is actually the case. In fact the resemblance of the basalt of the Dasses to the intrusive rocks of the Lion's Haunch, Dunsapie and Samson's Ribs suggests that this sheet may have been injected at a time subsequent to the establishment of the main orifice.

The description of the great teschenite sill of Salisbury Craigs * is given in another chapter (p. 276), since, from its petrographical character and from its disappearance in the field in thin branching veins in the direction of the larger vents, it almost certainly belongs to a slightly later period of igneous activity which followed after the complete extinction of the Arthur's Seat volcano.

The intrusive mass at Duddingston presents no point of special interest. It is a basalt of the Dunsapie type, whose intrusive character can be at once inferred from the manner in which it truncates the fine tuffs and calcareous bands that overlie the Loch Craig (Long Row) basalt.

The Castle Rock, though somewhat removed from Arthur's Seat, may, however, be dealt with in the present section. In character it is a fine-grained basalt of Dalmeny type resembling the rock of the Lion's Head, and, like it, may belong to the early part of the volcanic history of Arthur's Seat. It is manifestly a plug rising almost vertically through the Upper Old Red Sandstone, against which members of the Cementstone group are brought by faulting (Fig. 3). It is quite possible that the Castle Rock may have served as an orifice for the emission of lavas although no such connection can now be established.

* Prof. Bonney first separated the intrusions of Salisbury Craigs, Samson's Ribs and St. Leonard's Craig, *Proc. Geol. Assoc.*, 1878, pp. 503, 508.

VOLCANIC ROCKS OF CALTON HILL.

As was demonstrated by Sir Archibald Geikie, the Calton Hill is merely a portion of the volcanic platform of Arthur's Seat which has been shifted westwards by the Calton fault. The succession agrees closely with that of the Whinny Hill, but, as might be expected, shows local variations, especially in the greater development of ashes, wherein it approaches the sequence on the south side of the great vent in Arthur's Seat.

The dip of the volcanic rocks being in the same general direction as in Arthur's Seat, the lowest beds are exposed towards the west where they are underlain by the cementstones, the latter being truncated by the Colinton fault (Fig. 6). The basalt of the Long Row does not appear to have extended so far to the north, as the local base of the volcanic series exposed in street excavations consists of fine ashes intercalated with sediments of Ballagan type, and including at least one flow of basalt of Craiglockhart type. In a general way these represent the ashes and sediments of the Dry Dam and are in like manner overlain by porphyritic basalts also of Craiglockart type (xBd¹, Fig. 6). The first of these lavas possesses a central columnar belt passing upwards into a slaggy upper portion with cavernous spaces infilled with fine ashes and bedded limestones, thus presenting a striking similarity to the features of No. III lava of the Whinny Hill succession. Near the top of this group the lavas alternate with fine ashes and quartzose sandstones, as seen in road sections, the whole being overlain by a mass of well-bedded agglomerate containing numerous blocks of basalt of Markle type and occasional thin lenticles of lavas of similar composition (BZd¹, Fig. 6). From this

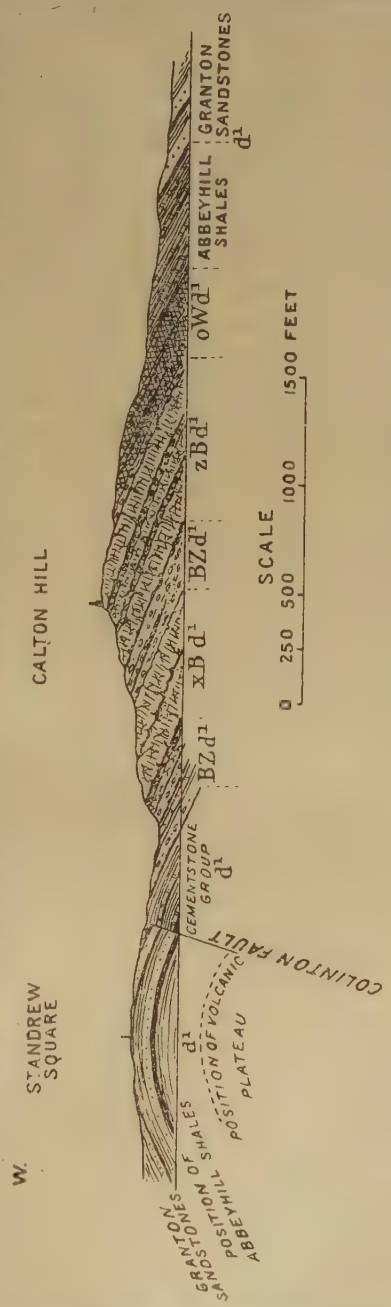

FIG. 6.—Section across the Calton Hill, Edinburgh.

point up to the National Monument several alternations of porphyritic basalt of Markle type with thin beds of tuff are well exposed (zBd^1, Fig. 6). This succession can be examined in the road section leading obliquely up the hill behind the High School and in the paths and cliffs overlooking the High Calton. The group ends with an ash band extending right across the hill and visible in all the road sections, which is succeeded by a typical platy mugearite lava (oWd^1, Fig. 6). Two similar flows separated by ash bands are to be seen in the road-cutting on the top of the hill outside the wall which divides the public grounds from the Regent Gardens. Rocks of this type make up the highest visible lavas of the Calton Hill, and in this instance there seems to be no reversion to lavas of Markle type, as in Arthur's Seat.

The volcanic rocks of the Calton Hill are overlain in natural sequence by shales of Ballagan type, containing entomostraca, which are exposed in the gardens behind Regent Terrace. In the No. I Borehole at Abbeyhill, recorded by Mr. John Henderson, a thickness of upwards of 300 ft. of dark shale was proved to overlie these volcanic rocks.* These sediments represent the highest members of the Cementstone group in the neighbourhood of Edinburgh.

VOLCANIC ROCKS OF CRAIGLOCKHART.

The volcanic rocks of Craiglockhart in the south-western suburbs of Edinburgh lie on the western limb of the anticlinal fold that runs through the city. They consequently dip towards the north-west, and like those of the Calton Hill are truncated by the Colinton fault. They give rise to two conspicuous craggy hills separated by a drift-filled hollow that follows the course of an unimportant fault. The best exposures are found on the western hill, where about 100 ft. of bedded ashes are overlain by a massive columnar lava of about equal thickness.

The tuffs are for the most part fine-grained, and almost entirely composed of small fragments of basalt, many isolated crystals of augite and olivine similar to those occurring in the overlying lava, and a slight admixture of quartz grains such as might have been derived from earlier formed sandstones. Occasional large blocks of basalt and sedimentary rock are not infrequent in the ash. Despite the well-bedded nature of the deposit no intercalations of normal sediment are observable, and it is quite probable that this deposit may have been formed as the result of a single eruption, as in the case of Monte Nuovo near Naples.

The basalt lava overlying this tuff has been taken as the rock-type of a widely distributed group occurring at or near the base of the Carboniferous system in Scotland. The junction of the lava and the ash is well exposed in the crags at both ends of the hill, the western crag just south of the Hydropathic Establishment affording the best section. The base of the lava does not quite conform to the underlying ash beds but here slightly transgresses them, probably indicating the actual breaking up of the soft floor over which the lava flowed. The contemporaneous nature of the rock is suggested by its extremely slaggy character in this exposure, and is confirmed by the abundance of veins and cavities infilled with fine ashes and

* *Trans. Edin. Geol. Soc.*, vol. viii. p. 7.

bedded limestone. Before the lava had cooled, some of the cavities appear to have been lined with a soft mud which has been baked and cracked by the residual heat, and the rents have been subsequently filled in with ash of a coarser texture. Other veins, infilled with jaspery substance, are abundant, but these are probably of later origin and similar to examples frequently found in intrusive rocks. These occur in the columnar massive portions where the infiltrations of true sediment can very rarely be found. The slaggy upper surface of the lava is well exposed at one point on the slope overlooking the ruins of the Castle, but the upward continuation of the volcanic series is lost at this point owing to the Colinton fault.

In the eastern hill the wider extension of the basement tuff is probably due to a slight roll over of the dip, and not to a thickening of the ash as might be supposed from looking at the Map. To the north of this hill the volcanic rocks seem to be faulted down against the edges of the Upper Old Red sandstones and marls exposed in the Myreside cutting of the Suburban Railway, near Craiglockhart Station. The tuffs and the basalt recall the lower part of the Whinny Hill succession of Arthur's Seat, but since the Craiglockhart ashes have no intercalations of normal sediment similar to those of the Dry Dam, it seems more probable that the Craiglockhart volcanic group was derived from a local centre and not from the Arthur's Seat vents. The great thickness of the Craiglockhart basalt tends to support this view. On this hypothesis it is not to be expected that the Craiglockhart volcanic rocks should have been strictly contemporaneous with those of Arthur's Seat. Evidence bearing on this interesting question has recently been supplied by some new exposures at the east end of the western hill, where sandstones and conglomerates and clay beds with calcareous concretions are seen in close proximity to the ashes, and dipping conformably with them. These beds strongly recall some of the rocks of the Craigmillar Sandstone group (Upper Old Red Sandstone), and, though this correlation has not been supported by fossil evidence, there is good reason for the belief that the Craiglockhart volcanic rocks are somewhat older than any occurring in Arthur's Seat, indeed they may actually lie at the junction of the Old Red Sandstone and Carboniferous systems, like the volcanic rocks of the Birrenswark platform of Eskdale and Annandale. B. N. P.

The Oil-Shale Group.

Owing to the discovery of thin seams of oil-shale in the Wardie Shales and in beds interleaved in the Granton Sandstone the base line of the Oil-shale group is now drawn at the bottom of the latter subdivision of the Calciferous Sandstone (see Fig. 2, page 52), instead of at the base of the Pumpherston Shales.

Only the three lowest members of the Oil-shale group, namely, the Granton Sandstone, the Wardie Shales, and the Hailes Sandstone are represented in this district. In the Royal Terrace Gardens, on the north slope of the Calton Hill, a massive bed of sandstone, forming the base of the Granton Sandstone, overlies shales full of entomostracan remains, belonging to the Cementstone group, the dip being to the north of east at an angle of 23°. Farther to the

east dark shales of Wardie type are exposed round the dolerite sill of Lochend.

These sections occur to the east of the great Colinton fault, to which reference has already been made (see Sheet 32), but the best exposures are to be found in the area west of this dislocation, and especially on the foreshore between Newhaven and the mouth of the river Almond. Sections are seen inland along the course of the Water of Leith near the Dean Bridge, and between Slateford and Juniper Green. Other exposures are to be found in the Suburban Railway cutting south of Gorgie Park Station, the cutting on the Barnton Railway near Davidson's Mains, and in the quarries at Craigleith, Hailes, Craigcrook and Davidson's Mains.

In this area the rocks have been thrown into a series of anticlines and synclines having a north and south trend, as was first pointed out by Mr. John Henderson.* One of these folds—the Granton anticline—extends from near Muirhouse on the coast west of Granton, southwards towards the southern end of Corstorphine Hill, and brings to the surface the Granton Sandstone and associated beds with a width of outcrop of over a mile between the quarries at Craigleith and Craigcrook.

A second fold—the Leith anticline—stretches from Leith Harbour to St. Andrew Square in the city of Edinburgh, and is truncated at its southern extremity by the Colinton fault. Its western limb has a steep inclination between Princes Street and the Dean Bridge where the junction of the Granton Sandstone with the overlying Wardie Shales is exposed. Between these anticlinal folds, a well-marked trough—the Wardie syncline—extends from the shore at Granton to the south of Hailes Quarry, in which lie the higher beds of the group, namely, the Wardie Shales and the Hailes Sandstone. In this trough the latter is only known to occur between Kingsknowe and Hailes Quarry, but it is probably also represented by the sandstones about the mouth of the river Almond, though the relation of these sandstones to the strata above and below has not yet been satisfactorily determined.

During the recent revision of this area oil-shales have been found to occur in these three divisions. An oil-shale containing fish remains overlies the sandstone in Hailes Quarry. A second band occurs in the railway cutting 100 yds. above Boags Mill on the Water of Leith, which probably lies in the Wardie Shales. A third oil-shale has been found on the south side of a new road running parallel with and immediately south of the Queensferry Road. Its locality is 60 yds. a little south of east of Ravelston Lodge, and the shales in which it occurs are intercalated in the Granton Sandstone. On the coast section between Granton and Wardie several oil-shales have been discovered. The analyses of some of these shales are referred to in the economic section of this memoir (p. 351).

The Wardie Shales are best exposed in the Wardie syncline on the shore between Trinity and the rock that projects seaward 330 yds. west of Granton Harbour, known as the General's Rock. The following vertical section of these strata, as there exposed, has been prepared to show the sequence of beds in relation to the oil-shales which they contain :—

* See J. Henderson, *Trans. Edin. Geol. Soc.*, vol. iii. p. 24, vol. vi. p. 29.

	Ft.	In.
Sandstones and grey papery shales	60	0
Oil-shale	6	0
Black and grey shale	20	0
Curly oil-shale (No. 3 analysis, see page 351)	6	0
Blue and black shale with thin band of volcanic ash	6	0
Oil-shale	2	0
Blue and black shale	8	0
Sandstone with *stigmaria*	20	0
Blue and grey papery shale	35	0
Oil-shale with entomostracan bands	6	0
Curly oil-shale (No. 2 analysis, see page 351)	6	0
Poor shale	6	0
Blue oil-shale	4	0
Shale with entomostracan bands	4	0
Sandstone and grey papery shale	12	0
Grey papery shale and thin ironstone bands	28	0
Oil-shale (No. 1 analysis, see page 351)	2	0
Sandstone	6	0
Nodular fireclay and thin coal	25	0
White sandstone	20	0
Black shale with plants	55	0
Black shale with fish, coprolites and balls	70	0
Thin grey band of volcanic ash	2 to 4	0
Black shale	25	0
Hard yellowish sandstone	12	0
Grey papery shales		
Coal, formerly worked at Wardie		
Black shales with black sandstones and dark limy beds. An oil-shale (No. 4 analysis) and a band containing marine fossils in close proximity near the base	200	0
Top of the Granton Sandstones at the General's Rock		

Three of the oil-shales of which analyses have been made lie within Granton Harbour: the fourth occurs near the General's Rock. A specimen from the thin band of ash beneath No. 3 oil-shale has been examined microscopically and found to be a tuff probably of basaltic origin.

The beds containing the ironstone nodules, so famous for their fish remains, occur low down in the group, and are to be found chiefly to the east and west of Granton Harbour. Most of the fossils have been obtained at the eastern end of the section near Trinity.

The relations of the strata along the shore between the General's Rock and the mouth of the river Almond are somewhat obscure owing to numerous gaps in the section. West of the General's Rock the projecting headlands are composed of sandstone, but the intervening sandy bays furnish little definite evidence beyond occasional exposures of shales. Lithologically they resemble the division of the Wardie Shales.

West of Muirhouse the shore section is largely occupied by beach deposits. A band of tuff, the relations of which are uncertain, is represented on the Map (Sheet 32) near Silverknowe, but it is believed to be intercalated in the lower portion of the Oil-shale group.

Brief reference will now be made to the inland exposures of the lowest members of the Oil-shale group to the south of the typical section on the shore. Within the city of Edinburgh, strata belonging to the Granton Sandstone group were pierced in the tunnel of the

Old Edinburgh and Granton Railway, which extended underground from the Waverley Station to Scotland Street. The course ran nearly north and south and slightly obliquely across the axis of the Leith anticline, the crest of which lies beneath St. Andrew Square. On the west side of this axis, the Granton sandstones and the accompanying dark shales with ironstone nodules containing coprolites and fish remains have been exposed from time to time during building operations. At the corner of St. David Street and Princes Street, sandstones and shales and a thin coal seam, dipping towards the north-west, were laid bare during the rebuilding of Charles Jenner & Co.'s premises. Dark shales with ironstone nodules, belonging to this group and dipping north-west at high angles, have, from time to time, been exposed in Hanover Street and Princes Street, and along the same strike to the south-west at St. Cuthbert's Church up to the Colinton fault. Similar beds, also dipping to the north-west, are still visible in the cutting of the Caledonian Railway. The gorge of the Water of Leith between Drumsheugh and Stockbridge has been carved in beds of this group, where they form the western limb of the Leith anticline as was shown by Mr. Henderson. Some of the highest beds in this section belong to the Wardie Shales.

Following the eastern limb of the Wardie syncline to the south-west we find beds belonging to both groups in the Suburban Railway cutting near Craiglockhart Station. On the north-west side of the Colinton fault dark shales with ironstone nodules, belonging to the Granton Sandstone group, are seen dipping at high angles to the north-west, which, to the north of the Station, are succeeded by sandstones and shales with a similar inclination, while a little farther north the presence of the marine band indicates the lower part of the Wardie Shales. This group here contains shales with occasional sandstone bands and two seams of coal, one of which reaches a thickness of about two feet but contains thin strains of carbonaceous fireclay. These coals probably represent those of Caroline Park near Granton and the seams formerly worked near Wardie. These rocks are hardened and altered by two sills of dolerite.

Strata belonging to these groups have been exposed north of Craiglockhart Hill, where they dip steeply to the north-west away from the Colinton fault. A coal exposed there in one of the quarries is probably the same as one of the seams in the Suburban Railway section.

The Water of Leith, between Colinton and Juniper Green, traverses obliquely the southern end of the Wardie syncline. On its eastern limb the Granton sandstones dip steeply off the fault at the eastern side of the large stretch opposite Colinton, the rocks being also much disturbed. Two marine bands are seen in the bed of the river at Curriemuir and Woodhall, which must lie in the Wardie Shales, a short distance above their junction with the underlying Granton Sandstone. From Curriemuir to Currie, where the Colinton fault crosses the Water of Leith, the Wardie Shales are to be found at intervals in the river banks with a uniform dip to the east, showing that the strata lie in the western limb of the Wardie syncline.

The highest members of the Oil-shale group in this district are

exposed in the Hailes Quarry, where the sandstones are inclined to the east at angles of 10° to 15°, and are overlain by shales containing a band of oil-shale, an account of the analysis of which is given in the economic section (Chap. XVII. p. 351). The sandstones reappear in the east limb of the syncline in a quarry about half a mile farther to the east, near Kingsknowe Station. Black shales of the Wardie Shales series are laid bare in the Water of Leith at Redhall, dipping to the west beneath the sandstone in the quarry at Kingsknowe.

As already indicated, the Granton anticline has been proved to extend southwards beyond Ravelston House by means of various exposures of the strata. On its eastern limb massive sandstones with an easterly dip have long been wrought in the famous quarries at Craigleith, where they pass beneath shales containing a calcareous band with marine fossils.

The Granton Sandstone has also been worked in quarries near Craigcrook Castle, where it is inclined to the south-east, and still farther south it dips in a southerly direction near the dolerite sill of Corstorphine Hill. Northwards near Davidson's Mains, on the west limb of the arch, the overlying Wardie Shales are in contact with the dolerite sill and are baked into a hard porcellanite, which has been largely quarried for road metal. They are also visible in the Barnton Railway cutting, a short distance farther north, with a similar westerly dip.

The Wardie Shales and Granton sandstones are related lithologically to the higher part of the Oil-shale series in which the oil shales are now worked, and the assemblage of fossils, consisting chiefly of fish and plant remains with a scarcity of marine types, is similar. Reference has already been made to the marine bands in the Wardie Shale series recorded by the older observers. They occur in the shore section near the base of the Wardie Shales at the General's Rock, at Drumsheugh and the Dean Bridge in the Water of Leith, at Woodhall and Katesmill above Colinton, in the shale overlying the sandstone in Craigleith Quarry, in the excavation on the east side of the northern end of Corstorphine Hill, in the Suburban Railway cutting west of Morningside Station and in the cutting of the Barnton Branch Railway near Davidson's Mains. Mr. Henderson, who was the first to call attention to these bands, considered that in most of these localities they belong to one horizon near the base of the Wardie Shales. Those in the quarry at the north end of Corstorphine Hill and in the Barnton Railway cutting were referred by him to a different position, but the field evidence seems to support the view that they represent the band near the base of the Wardie Shales.

The fossils from these zones in the cabinets of Mr. John Henderson and Mr. Gall, Edinburgh, were described, as already indicated, by Mr. R. Etheridge, Jr. (see p. 49). Marine but not open sea conditions are proved by the occurrence of such brachiopods as *Lingula* and *Discina* and by cephalopods such as *Orthoceras*. Lamellibranchs and gasteropods also occur. The whole assemblage is similar to the organic remains found in the marine bands in the Lower Carboniferous rocks of East Fife, which stratigraphically represent the Oil-shale group.

C. B. C.

CHAPTER VIII.

CALCIFEROUS SANDSTONE SERIES OF THE QUEENSFERRY, BROXBURN AND WEST CALDER DISTRICT.

THE area extending from the shores of the Firth of Forth southwards to the Pentland Hills, which now falls to be described, is bounded on the east by a line drawn from the mouth of the river Almond to the village of Currie on the Water of Leith. Its western limit is defined by the outcrop of the Hurlet Limestone, which runs approximately in a north and south direction from a point in the Firth west of Blackness Bay southwards to Cobbinshaw Reservoir. It thus embraces the rich oil-shale fields of the Lothians between Queensferry and West Calder—the centre of the oil-shale industry in Scotland.

The sequence of strata in this district ranges from the base of the Cementstone group to the top of the Calciferous Sandstone series, the most striking feature of the region being the remarkable development of the shale measures. The volcanic rocks of Arthur's Seat are here represented by the basalt and mugearite lavas of Corston Hill, where they are associated with cementstones of Ballagan type. At Dalmeny and Dechmont there is evidence of brief outbursts of volcanic activity during the deposition of the Oil-shale group before the extrusion of the great succession of lavas and tuffs of the Bathgate Hills.

The upper portion of the Calciferous Sandstone series, as already indicated, dips westward under the Carboniferous Limestone series of Bo'ness and the Bathgate Hills. The exact position of the boundary line between the two is often obscure, partly owing to the great covering of drift and partly because of the variability of the strata, which often renders correlation impossible even across areas only a few miles in breadth. Still more difficult is it to correlate the beds in this western district with those in Mid-Lothian or along the Haddingtonshire coast.

The two Abden Limestones of Kinghorn, Fifeshire, bear considerable resemblance to the Longcraig Limestones on the coast east of North Berwick, which are about 25 mls. distant in an E.S.E. direction, and it seems probable that the Lower Abden is on much the same horizon as the Lower Longcraig—the limestone, which, in East Lothian, is taken as the basement bed of the Carboniferous Limestone series. In Fifeshire, however, in the one-inch map 40, the base of this series has been drawn at the bottom of the thick limestone, exposed on the coast a little west of Seafield Tower, which comes next above the Abden beds, and has been regarded as the equivalent of the Hurlet Limestone by Sir A. Geikie.*

* "Geology of Central and Western Fife and Kinross-shire," *Geol. Sur. Mem.*, p. 91.

Between Kinghorn and Charlestown in Fife, great changes in the lithological character of the strata supervene, and, as will be subsequently shown, the different limestones in these two districts cannot be correlated with confidence. The bed adopted as the base of the Carboniferous Limestone Series at Charlestown has been correlated on the south side of the Firth of Forth with that at Whitebaulks, and the latter has been followed at intervals along the strike as far as Bathgate with considerable certainty. The tracing of this base-line has been aided by the almost continuous outcrop of the Hillhouse and Petershill Limestone for more than four miles between Hiltly and Bathgate. South of Bathgate the volcanic rocks disappear, and at the same time the limestones change their characters, which increases the difficulties in their correlation. In this southern area, the limestone at Cobbinshaw, which has been identified with the Hurlet, has been taken as the basal bed of the Carboniferous Limestone series.

It is necessary to bear in mind that subordinate beds of marine limestone occur considerably below the base of the Carboniferous Limestone series in West Lothian as well as elsewhere, and that there is no palæontological break at the base. C. T. C.

The geological structure of the shale measures of West Lothian and the adjoining part of Mid-Lothian presents certain general features which may now be briefly indicated. Throughout the greater part of the region the strata are arranged in a series of sub-parallel folds, the axes of which generally run in a N.N.E. and S.S.W. direction, whereby the oil-shales are spread over a belt of country several miles in width. These arches and troughs are traversed by several more or less powerful faults, traceable for miles, which, at certain localities, produce large displacements of the strata.

The Main Faults.—In this district there are four important dislocations, all of which have a general easterly or north-easterly trend, and, with one exception, have a common downthrow to the north. The detailed mapping of the region has proved that though they profoundly affect the geological structure of the various mining districts, the axial folds can in many cases be traced across their path.

The most northerly one, the Ochiltree fault, whose downthrow is to the south, begins a short distance to the south of Wester Ochiltree, and, passing north of Duntarvie and Dalmeny Church, enters the Firth of Forth at Drum Sands. The next dislocation is the Middleton Hall fault, which originates near Dechmont House and extends eastwards by Middleton Hall to Ingliston. Still farther south we find the Calder fracture, which begins to the north of Baad's Mill, and passes by the south of West and Mid-Calder in the direction of Currie. It is regarded as a south-west branch of the Colinton fault. The fourth important line of disruption is the Murieston fault, which bounds the north side of the Wilsontown coal-field, and enters Sheet 32 to the west of Cobbinshaw reservoir. It truncates the volcanic rocks of Corston Hill on the north and joins the Calder dislocation near Dalmahoy House.

The Main Flexures.—On the north-west side of the West Cairn Hill in the Pentland Chain the Upper Old Red Sandstone and

Calciferous Sandstone strata dip gently to the north-west for about three miles from the watershed, where they form the southern limb of a shallow syncline extending from Cobbinshaw reservoir to Dalmahoy Hill. Here the trough bends to the south-east round the Haugh Head arch and forms what may be termed the Balerno basin. North of this fold between Corston Hill and Selms the cementstones and the higher beds of the Upper Old Red Sandstone are again brought to the surface by a fold, which is truncated by the Murieston fault.

The most prominent of the anticlinal folds is that of Pumpherston, about midway between the Firth of Forth and Cobbinshaw reservoir, in the centre of which lie the lowest workable oil-shales, in the form of a narrow ellipse, whose major axis runs north and south for two miles (see Sheet 32). On either side of this arch the strata form deep synclinal folds. The eastern basin, which underlies the drift-covered plain of Drumshoreland Muir, trends southwards for three miles to Mid-Calder (Fig. 7, p. 88). The western trough, extending from Pumpherston beyond Houston Wood to Dechmont, is broad and deep, being covered in the centre by a sheet of intrusive dolerite 200 ft. thick. This basin, which has an outcrop of the Burdiehouse Limestone on either side, runs northward for a distance of three miles from the river Almond at Livingston to Uphall.

North of the Middleton Hall fault the Pumpherston anticline is continued in the low arch that extends from Broxburn to Niddry, and the deep basin that stretches northwards from Middleton Hall to Newbigging is beyond doubt the northern prolongation of the trough west of Pumpherston. The eastern trough is represented by the shallow basin which has been proved by mining operations to occur at East Mains.

North of the Ochiltree fault, the well-marked anticlinal fold at Hopetoun House and the adjoining Duddingston basin to the east may be the northern continuations of the Pumpherston and Mid-Calder flexures respectively (Fig. 9, p. 96).

In the southern portion of the district, between Livingston and Cobbinshaw reservoir, the West Calder shale-field is of great economic importance owing to the repetition of the various oil-shales by folding and faulting. The principal tectonic features are two deep basins at Polbeth and Hartwood respectively, with an intervening low anticlinal ridge at West Calder village.

Along the western border of this district the members of the Oil-shale group roll over an anticlinal fold which has been traced from West Harwood northwards by Burngrange, Mid-Breich, Dechmont, and Hangingside to Philipstoun Mill, where with a low pitch to the north-east it disappears.

Cementstone Group.

The members of the Cementstone group and associated volcanic rocks occurring within this district may be arranged in the following descending order:—

d. Dark grey shales containing remains of fishes, plants, and entomostraca; black shales with fireclay and ironstone bands, coarse sandstones, and cementstone bands with intercalated beds of tuff.

c. The volcanic rocks of Corston and Torweaving Hills representing the later part of the volcanic series of Arthur's Seat.
b. Conglomerate, purplish, red, yellow, white, and grey sandstones containing plant remains, with grey and green shaly partings.
a. Hard calcareous shales, soft red and green marls, with ironstone and cement bands.

(*a*) An excellent section of the lowest subdivision is laid bare in the Linhouse Water to the north and west of Blackraw and about a mile and a half south of Mid-Calder. The lowest beds exposed are not far above the quartz dolerite sill of Selms which has been injected near the base of the Cementstone group. In this stream the strata present the characteristic features of the cementstones of Ballagan type, and are succeeded by a prominent bed of hard conglomeratic grit. North-eastwards red and green marls are to be found in the Gogar Burn, but between this point and the junction of the Mid-Calder and Murieston faults there are no exposures of strata on this horizon.

On the south side of the Cobbinshaw and Dalmahoy syncline the members of this subdivision are laid bare near the head of East Colzium Burn, where the red and grey marls contain cement bands, one of which was sufficiently thick to be quarried for lime.

Along the north-west slope of the Pentland Hills exposures of the basal portion of the cementstones are rarely met with, and hence the base-line of the Carboniferous rocks represented on the map is here to a certain extent conjectural. They are laid bare, however, in burns draining into Threipmuir reservoir from the south-east and round the Clubbiedean reservoir, where they resemble lithologically the strata on this horizon in the city of Edinburgh. At the latter locality they contain a marine band, to which reference was made in the previous edition of this memoir.*

(*b*) In the Linhouse Water the band of hard grit at the top of subdivision (a) is followed by red and green marls which pass upwards into purplish, red, and yellow sandstones (b) with a fine brecciated conglomerate containing fragments of the Lower Old Red Sandstone volcanic rocks of the Pentland Hills. This conglomerate, which has been traced to the east of Corston Hill, passes underneath the representatives of the volcanic series of Arthur's Seat.

On the south side of the Cobbinshaw and Dalmahoy syncline this subdivision is only exposed in two sections. In the Mid-Crosswood Burn, red and grey sandstones underlie the volcanic zone of Torweaving Hill, and between Harperrig reservoir and Dean Burn there are a few exposures of shaly sandstone and blue shale.

J. S. G. W.

(*c*) As already indicated, the lavas and tuffs of Corston Hill point to the existence of a volcanic centre in that neighbourhood which was active about the same period as the Arthur's Seat volcano and produced a similar suite of rocks.

Here again coarsely porphyritic basalts are found associated with fine-grained non-porphyritic mugearites. All the specimens examined microscopically from this area belong to either one or the other of these two categories with a predominance of the

* "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, pp. 18 and 144.

mugearite type.* Fuller investigation in the future may prove that some of the rocks, which have been provisionally classed with the mugearites on the ground of their field characters alone, may belong to some other group.

Owing to the synclinal structure of this part of the area, the volcanic rocks possess a double outcrop open to the west and converging to the east, and in part truncated to the north by the Murieston fault.

The greatest development occurs in the Corston area. The local base of the series is exposed in the Linhouse Water, half a mile west of Corston farm, where a mugearite lava rests on a conglomeratic grit, which in turn overlies a typical development of clays and cementstones. Immediately to the east a porphyritic basalt with conspicuous felspar phenocrysts forms the base of the series for a distance of two miles, and gives rise to the conspicuous escarpment of Corston Hill figured by Sir Archibald Geikie.†

The basalt is capped along its course by a succession of mugearite lavas which have been traced farther to the east than the basalt and extend in this direction at least as far as Newlands. The upper portion of the series, consisting also of mugearites, is exposed in the Linhouse Water and in the small tributary from the east in the neighbourhood of Midton. Northwards three lava flows of similar character, separated by thin bands that resemble flow-breccias, but may be true ash deposits, crop out in the railway cutting. A little farther to the west the Murieston Water exposes the top of the volcanic group consisting of a mugearite lava with a ropy and much-involved upper surface overlain by alternations of sandstones and ashes containing fragments resembling the lava. These are in turn overlain by sandstones, dark shales, and ironstone bands.

Similar ashes are exposed at a bend of the Linhouse Water a little to the north of the line of the Murieston dislocation. Viewed in connection with the overlying strata, it seems probable that this exposure belongs to a small inlier of the Corston Hill volcanic rocks. This inference is supported by the absence of oil-shales and the Burdiehouse Limestone in this neighbourhood as shown by bores. On the south side of the syncline of which Corston Hill is the northern limb, the volcanic rocks are much less fully represented and are separated by considerable masses of sediment, showing that the volcano to the north had a long period of existence. The lowest volcanic rocks here exposed are mugearites forming the Torweaving and Black Hills (see Sheet 32). A good example of a slaggy mugearite of this band is seen near the junction of the burns at East Colzium, where it is underlain by an important sandstone with clays and cementstone bands. Near Colzium the mugearites pass under a porphyritic basalt resembling the lowest bed of Corston Hill. At a higher horizon, and separated from the mugearites of Torweaving Hill by sedimentary strata, there occurs an apparently isolated, very slaggy, porphyritic basalt. After another considerable interval, probably occupied for the most part by sedimentary strata, a thick bed of tuff is exposed in the Crosswood Burn resting on a

* Localities from which specimens of mugearite have been obtained and determined microscopically are referred to in Chap. XV. p. 322.

† "Ancient Volcanoes of Great Britain," vol. i. p. 373.

conglomeratic sandstone. It is overlain by sandstones and shales containing a coal seam that has been proved by boring to be 75 fathoms beneath the "Raw Camps" Limestone, identified with the Burdiehouse Limestone of the Mid-Lothian Coal basin.

East of Colziun, the volcanic group is only traceable by means of isolated exposures as indicated on the map by a broken line. The evidence, though very fragmentary, shows that there is a great attenuation of the volcanic products in this direction.

B. N. P.

(*d*) The highest members of the Cementstone group in this area are found above the volcanic rocks of Corston Hill in the Murieston Water at Skivo. They consist of fossiliferous grey and black shales with intercalated ash beds and one thin limestone of Burdiehouse type, which dip below thick grey and yellow sandstones with fragments of coal similar to those of Granton. At Little Vantage bands of cementstone with grey blaes rest on coarse pebbly sandstones. In the Green Burn, south of East Newton, light brown and yellow sandstones with a thick cement band dip to S.E. On the north side of Dalmahoy Hill similar sandstones were quarried together with two cement bands, which were burned for lime.

On the south side of the Cobbinshaw and Dalmahoy syncline in the Shear and Crosswood Burns, green, grey, and purple sandstones with varying dip are overlain by coarse conglomeratic sandstone containing fragments composed chiefly of radiolarian chert. In the Crosswood Burn this conglomerate was quarried at the foot of the water tower in the Crosswood reservoir and used in the building of the walls that surround this sheet of water. In the Shear Burn a bed of sandstone rests upon this conglomerate, which in turn is covered by a fine, greenish grey, well-bedded tuff, containing fragments of cementstone with plant remains. It probably represents the top of the Arthur's Seat volcanic zone. A fault with a downthrow to the north repeats this bed at the junction of the Shear and Crosswood Burns. It is not seen to the north of this locality, but the underlying conglomerate has been traced to near Camilty Mill.

In the Water of Leith, 400 yds. east of Haugh Head farmhouse, there is a good exposure of a coarse conglomerate with numerous fragments of radiolarian chert and other rocks, similar to the bed already described in the Shear Burn. It is overlain by a bed of ash covered with red and yellow sandstones of considerable thickness, and green and purple marls with hard calcareous sandstones. In the burn south-west of Cockburnhill the same ash bed and conglomerate are again exposed dipping to E.S.E.

The ground between Camilty and Wester Causewayend has been pierced by numerous bores, and the strata between these two points may represent the upper portion of the Ballagan beds with several thin coals.

The Oil-Shale Group.

The order of succession of the strata composing the Oil-shale group and its important zones are shown in the vertical section Fig. 2 (p. 52). At present no bands are worked below the horizon of the Pumpherston Shales, though several seams of inferior value occur in the lower subdivisions down to the Granton Sandstone.

In the economic memoir on "The Oil-Shales of the Lothians" (1906), detailed descriptions with horizontal sections were given of the various shale-fields, which need not here be repeated. It will be sufficient for our present purpose if we select for special reference the shale-fields of Pumpherston and West Calder and the shore section on the south side of the Firth of Forth, as illustrative of the geological structure and development of the workable oil-shales.

The three lowest subdivisions of the group—the Granton Sandstone, Wardie Shales, and Hailes Sandstone—are not typically represented in this district. In the Murieston Water, the highest members of the Cementstone group are overlain by thick sandstones with pebbly bands, which probably represent the Granton Sandstone. This arenaceous zone contains a thin coal, has a general dip to the south-west, and is repeated by a fault. At Broadshaw Bridge these sandstones dip below black and green sandy shales with plant remains which represent the lower portion of the Wardie Shales. These shales and sandstones are repeated by a fault, and, in a short distance, a second dislocation brings up the sandstone which continues with undulations as far as the bridge across the Murieston Water, about a mile up stream from Broadshaw.

In the Shear Burn, a coal seam, six inches thick, associated with fakes and sandstone, occurs 20 ft. above the volcanic ash, and this seam has been proved by boring to lie 75 fathoms below the Burdiehouse Limestone. It has been traced to Crosswood Burn House, where a bore has proved that a second thin coal occurs nine fathoms above it. These coals are probably on the horizon of the thin seam associated with sandstones in the Murieston Water.

Between the Linhouse Water and the outcrop of the Burdiehouse Limestone at Harburnhead no natural section is available, but the ground has been extensively bored south-west of Harburn and around Camilty Hill.

The lowest beds at Camilty Hill are fakes, blaes, and bands of sandstone with a bed of conglomerate and a limestone two feet thick. At Harburnhead these appear to be covered by a series of blue shales with ironstone bands followed by thick sandstones. Higher up we find a mixed series of fakes and shales with one thin band of limestone, above which come two beds of conglomerate overlain by a succession of blaes and fakes with three thin limestones. Between this horizon and the base of the Burdiehouse Limestone, sandstones, sandy fakes with shales and three thin limestones intervene. This series of strata, about 400 ft. thick, comprises beds from near the base of the Burdiehouse Limestone down probably to the horizon of the Wardie Shales without any representative of the Pumpherston Oil-Shales.

AREA SOUTH OF MID-CALDER BETWEEN THE MURIESTON AND CALDER FAULTS.

The strata exposed in the Linhouse and Murieston Waters between the Calder and Murieston faults to the south of Mid-Calder lie below the Burdiehouse Limestone. In the Linhouse Water the lowest member is the bed of soft green and yellow felspathic ash which dips to south-east a little below the Oakbank Oil Works. As already indicated, it probably represents the upper limit of the volcanic rocks

of Corston Hill. The ash is succeeded by 300 ft. of thin sandy shales, cementstones, and sandstone bands with plant remains, and these beds may be correlated with the highest beds of the Cementstone group. These strata dip beneath thick white sandstones with shale and ironstone partings, which are regarded as the equivalents of the Granton sandstones. Before the establishment of the Oakbank Oil Refinery this sandstone group was extensively quarried to within a short distance of the Murieston fault, which is well exposed in the bottom of the ravine and brings the upper portion of the Granton sandstones against the basement beds of the Cementstone group.

Just beyond its northern exposure in the Linhouse Water the ash bed is intersected by a fault with a downthrow to the north; but the Granton sandstones, with pebbly bands and a bed of grey limestone with oolitic structure, all dipping in an easterly direction, occupy the stream section to the Calder fault.

Between Hoghill and East Langton several trial pits have been sunk, which proved black shale, probably representing the position of the Wardie Shales, in a shallow syncline, and, at the latter spot, the sandstones again rise to the surface.

RIVER ALMOND SECTION FROM CLIFTON HALL TO ALMONDELL.

From the railway viaduct near Clifton Hall to where the Burdiehouse Limestone crosses the river Almond at East Calder, there is an excellent exposure of the strata for some distance below the Burdiehouse Limestone. Between the viaduct and the bend of the stream below the canal aqueduct a broad band of black shales crops out along the western bank. The bed of the river is occupied by a basalt sill intruded along the bedding planes of the shales, which are burnt. These strata represent the upper portion of the Pumpherston Oil-shale group and dip below shales with ironstone bands succeeded by sandstones with partings as far as the second basalt sill, which lies to the south-east of Illieston. From this point to the sharp bend in the stream to the south-west of Illieston the section is composed of black shales with ironstone bands and nodules containing fish remains with a few thin beds of sandstone. From the Pumpherston Shale position at Lins Mill to this point, the dip, with the exception of one small fold, is to the west, and here the top of the Pumpherston Shales probably lies 350 ft. below the bed of the stream.

In the portion of the river between the bend south-west of Illieston and the ford, flat beds of brown sandstone, shales, and sandy fireclay are seen, and from the ford to the next bend at Drumshoreland Muir no strata are visible. In this part of the river-course the dip must be to the east, for just opposite Almondell the highest oil-shale band of the Pumpherston group appears. This bed sharply rolls over to the west, and there is a steady ascending section as far as the outcrop of the Burdiehouse Limestone to the north of East Calder. The lower portion of this part of the section is a repetition of that already described on the east side of the syncline, and the upper portion consists of thick beds of brown, grey, and flaggy sandstones, succeeded by bands of kingle or indurated sandstone, and shales with ironstone and fake partings.

PUMPHERSTON SHALE-FIELD.

One of the most perfect anticlines of the shale measures is the arch of Pumpherston, which brings to the surface the lowest pro-

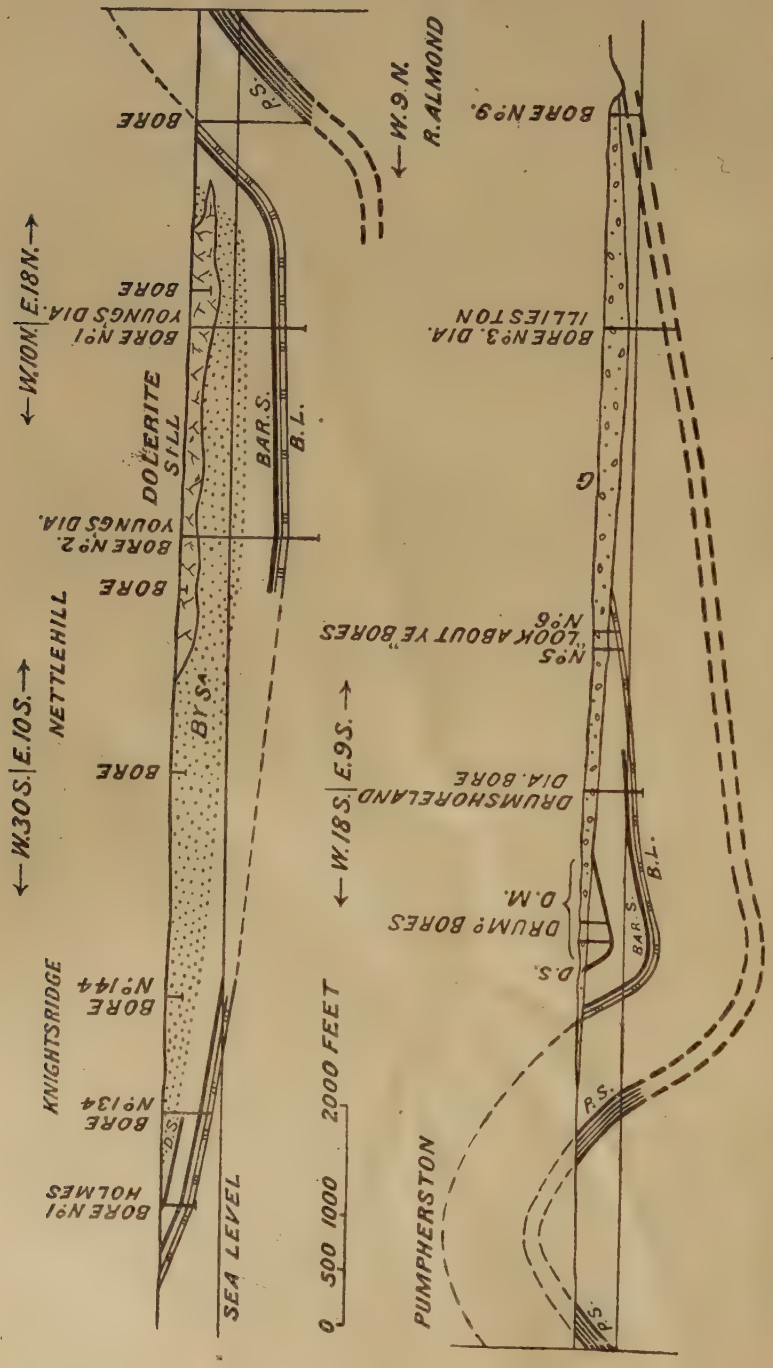

Fig. 7.—Section from Nether Dechmont and Knightsridge to Illieston and the River Almond.

ductive seams as yet worked in the Lothians. This field is of exceptional geological interest, as it defines the position of the Pumpherston Shales relatively to the Burdiehouse Limestone.

The only natural section in this district is the outcrop of the oil-shales and underlying beds in the Caw Burn, but the structure of the field has been thoroughly proved between Powflats and Pumpherston by the numerous mines, pits, and bores which have been driven, sunk, and drilled over this area.

Between the Edinburgh and Bathgate Railway and a point to the north of Pumpherston farmhouse the anticlinal axis runs almost due north and south. About 700 yds. to the north of the latter locality the beds begin to pitch to the south, and in the shale workings the inclination reaches an angle of 25° to 30°. Hence the shale outcrops on each side of this fold wheel round rapidly to the south and meet each other about 400 yds. to the north of the farmsteading.

On the north side of the Pumpherston Oil Works the beds begin to pitch to the north about 500 yds. from the Edinburgh and Bathgate Railway. At this end of the arch the angle of pitch is low, and hence the east and west outcrops of the five seams forming the Pumpherston Shale group spread out as they bend round the northern portion of this fold.

On the west side of the arch the dip of the Burdiehouse Limestone is 45° for a vertical distance of 680 ft. from the surface, and at this point, without any break, the limestone and Barracks Shale become first flat, then gently rise with an easterly dip and appear on the west side of the Houston Wood basin (Fig. 7).

On the east side of the Pumpherston anticline the dip at first is not so steep as on the west side. Not far below the surface this inclination rapidly increases, and where the strata plunge under the west side of the Clapperton Hall basin, the beds become vertical and for some distance are inverted.

Section of Pumpherston Shale-field compiled from Pumpherston Bores.

	Ft.	In.
Shale, Barracks	7	0
Limestone, Burdiehouse	20	0
Strata—chiefly sandstones, some of the beds 18 ft. thick, with fakes and thin limy sandstone partings	330	0
Strata—chiefly hard fakes and dark blaes with ribs. A few thin sandstone beds intervene	126	0
Shaly blaes and thin bands of oil-shale, very inferior quality	8	0
Strata—chiefly hard fakes and dark blaes with ribs	106	0
Strata—dark blaes, faky blaes with faky sandstone partings	210	0
Oil-Shale No. 1, or Jubilee Seam	7	0
Blaes	14	0
Oil-Shale No. 2, or Maybrick Seam	5	3
Blaes and balls with ribs	13	6½
Oil-Shale No. 3, or Curly Seam	7	5½
Fakes and blaes	22	0
Oil-Shale No. 4, or Plain Seam	7	8
Blaes	2	8
Oil-Shale	1	5
Blaes with ribs	5	10

	Ft.	In.
Oil-Shale No. 5, "Wee" or Under Shale	4	3
Dark and sandy blaes with fake partings	32	6
Shaly blaes	1	8
Hard dark blaes	2	4
Shaly blaes	3	4
Blaes and balls	5	6
Shaly blaes	1	8
Dark blaes	3	10
Shaly blaes	4	8
Dark blaes and balls	10	0
Soft blaes with ribs	11	9
Grey fakes	1	10
Marl and marly fakes	41	0
Grey fakes with ribs	25	6
Hard grey sandstone	7	8
Grey sandstone	15	6
Hard sandstone and limy fakes	12	0
Grey sandstone and limy bands	21	8
Marl, grey and dark	8	0
Dark blaes	3	1
Fakes and blaes with sandstone and limy ribs	12	4
Hard grey sandstone	1	0
Blaes and ribs	3	4
Grey sandstone fakes and ribs	7	0
Blaes and grey sandstone ribs	6	0
Grey fakes with limy and sandstone ribs	8	0

The above section shows that beneath the Pumpherston Shales 250 ft. of strata have been proved by boring. The lower portion of these beds consists of thick grey and hard sandstone with some beds of shales, fakes, and grey marl. It is possible that this siliceous series may represent the higher portion of the Hailes Sandstone. These beds are overlain by a thick bed of marl and marly fakes, and between this and the lowest shale (No. 5) of Pumpherston there are four separate beds of shaly blaes.

Pumpherston Shales.—These shales comprise a group of five workable seams and are remarkable for their richness in ammonia, the yield with the best form of retorts being from 50 to 60 pounds of sulphate of ammonia with 20 gallons of oil per ton. The plain portion of No. 3 seam below the "curly" part has furnished a large number of well-preserved fossil fishes determined by Dr. R. H. Traquair, F.R.S., and the shale below the "Wee" band or No. 5 Oil-Shale contains well-preserved plant remains which have been named by Dr. R. Kidston, F.R.S.

None of the Pumpherston seams is worked at present on the south, east, or west sides of the anticline, but at the north end all the beds, with the exception of the Maybrick, are worked by the Broxburn Oil Company at the Roman Camp Mines. This company has driven a mine from the south side of the Edinburgh and Bathgate Railway in the direction of Powflats, which intersects the large east and west dolerite dyke. These shales have been proved by boring to lie to the north of Powflats and probably extend as far as the Middleton Hall fault. To the east and north-east of Pumpherston this shale group and two basalt sills which lie at the top and bottom of this series have been proved by diamond bores at Illieston. The highest of these intrusions is exposed in the bed of the river Almond, and both have rendered the shales useless.

The Pumpherston Oil Company put down a series of bores during

1905–6 by the hand rig diamond boring machine between the Burdiehouse Limestone and the Pumpherston Shales. These showed that for 200 ft. above the shales the beds consist of dark faky shale with oil-shale streaks and faky sandstone partings, which are succeeded by over 200 ft. of hard fakes and dark blue shales with ribs or "kinglestone." Near the centre of this series, or 456 ft. below the Burdiehouse Limestone, lies a band of fissile shale 8 ft. thick, with thin plies of oil-shale of very inferior quality. For 330 ft. below the Burdiehouse Limestone the strata are chiefly sandstones, some of the beds attaining a thickness of 18 ft. The Burdiehouse Limestone is not exposed around the Pumpherston anticline, but its position has been defined by numerous bores, and on the west side of this fold it is about 20 ft. thick.

WEST CALDER SHALE-FIELD.

The West Calder shale-field includes the area that is bounded on the east by the Murieston fault and on the west by the outcrop of the Hurlet Limestone. It displays the sequence of workable oil-shales from the Burdiehouse Limestone to the base of the Carboniferous Limestone series, as shown in the subjoined table.

General Section of West Calder Shale-field.

	Ft.	In.
Hurlet Limestone and Coal.		
Strata—blaes, ironstone ribs, thin coals, with bands of pebbly sandstones	450	0
Raeburn Shale	9	11
Strata—blaes, fireclay, fakes, and ironstone bands, 126 ft. to	150	0
Mungle Shale, 1 ft. 7 in. to	2	0
Strata—blaes, fakes, fireclay, and ironstone bands	130	0
Two-Foot Coal, 7 in. to	1	2
Strata—104 ft. to	230	0
Grey Shale	1	8
Strata—fireclay, with blue partings	73	0
Houston Coal in bands, 4 ft. to	6	0
Strata—thin laminated sandstone, dark flaky blaes, and clayband ironstones, 150 ft.	200	0
Fells Shale, 2 ft. 6 in. to	7	0
Strata—Broxburn Marls, 250 ft.	275	0
Broxburn Shale, 4 ft. to	6	0
Strata—including Hermand or Binny Sandstone	420	0
Dunnet Shale, 6 ft. to	10	0
Strata	52	0
Shale (New ?)	4	6
Strata—green felspathic sandstones, with conglomerate bands and shale partings, about	600	0
Barracks Shale	4	0
Burdiehouse Limestone	40	0

The accompanying horizontal section (Fig. 8) is drawn across the northern portion of the West Calder shale-field from Limefield Mains in the east to Addiewell Bridge in the west. It shows the low anticlinal fold which brings the Broxburn Shale to the surface close to West Calder. To the north-east and north-west of the village the strata lie in a series of shallow synclinal folds, while to the west the upper seams have a general westerly dip, and, after a series of gentle undulations, pass under the overlying Hurlet Limestone.

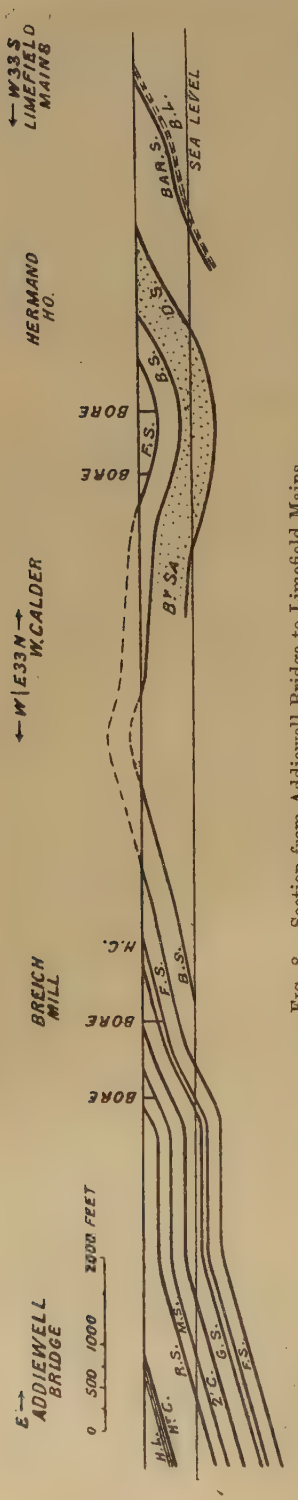

Fig. 8.—Section from Addiewell Bridge to Limefield Mains.

Burdiehouse Limestone. — On the east side of this field the Burdiehouse Limestone, 40 ft. thick, is exposed in the railway cutting at Blackmire. It is a typical freshwater limestone, and is overlain by 500 ft. of strata composed of green felspathic sandstones with fine conglomeratic bands and shale partings. The limestone is repeated by a north-easterly fault, and crops out in the Harwood Water above Limefield House with the Barracks Oil-Shale from four to six feet thick.

Dunnet Shale.—In the Harwood Water 600 ft. of siliceous strata with beds of green and red marls separate the Burdiehouse Limestone from the Dunnet Shale. There is an excellent exposure of this seam in the stream to the north of Hermand House, where it is covered by the characteristic Dunnet Marls. In a mine to the north, this shale shows the following section :—

	Ft.	In.
Roof, shaly blaes.		
Shale, plain	4	4
„ curly	2	0
„ plain	2	8
	9	0
Pavement, blaes.		

Binny Sandstone.—The Dunnet Shale is succeeded by the Binny Sandstone, about 400 ft. thick, which consists of thick beds of sandstone resting upon and overlain by black shales with ironstone and faky bands. In the Broxburn district these shales are represented by marls.

Broxburn Shale.—The outcrop of the Broxburn Oil-Shale is not seen in the Harwood Water, but in a mine near Chapelton the following is the measured section :—

	Ft.	In.
Shale (top)	0	5
Blaes	0	10
Fake	0	11
Shale (good)	3	7
Rib, blue	0	6
Shale (bottom)	0	8
	6	11
Pavement, fireclay.		

A glance at the map shows that this shale comes to the surface to the south-west of West Calder upon the centre of an elongated anticlinal fold. This portion of the Broxburn seam has been recently opened out. At first it proved irregular, but when followed to the dip the quality of the oil-shale improved. These shales have always been of an inferior quality in the West Calder district. The average thickness of the Broxburn seam is generally less than three feet with a yield of about 20 gallons of oil per ton. In the district around Burngrange several bores proved a coal, two inches thick, beneath the shale.

Broxburn Marls.—The Broxburn Marls, estimated to be 250 ft. thick in this district, are not exposed in the northern portion of the West Calder field, but on the south side of the Calder fault there is a good section of them in the Harwood Water just above the point where the stream is crossed by the West Calder and Harburn road. Here the beds are chiefly bluish and greenish grey shales and marls, with numerous bands of shaly sandstone, alternating with ribs of hard cementstone, which vary in thickness from one to three feet. Towards the top of these marls, shales with ironstone bands occur together with a bed of coarse dark limestone, yielding *Lepidodendron*, fish scales, and entomostraca. At the top of these shales lies the well-known cream-coloured unfossiliferous limestone which constitutes the index to the Fells Shale.

Fells Shale.—To the north-east of West Calder this seam fills a shallow basin towards the centre of which there are several faults which proved very troublesome to mining operations in the past. North-west of the village another basin has been largely mined, where this seam, about four feet thick, was found to consist of soft and hard bands. Here the Fells Shale has been worked across an anticlinal ridge which does not bring the shale to the surface. The flexure is accompanied by a want and several minor folds. No information has been obtained regarding the area to the south-east of West Calder, and the shale outcrop as shown on the map is there indefinite.

The Fells Shale, known in the early stages of the oil-shale industry as the "Thick Shale of Addiewell," has always been the principal oil-producing seam in the West Calder district. It varies from 2½ to 3½ ft. in thickness, but in some portions of the field reaches 7 ft.

In sinking a pit to this seam near Blackbrae, a fossil tree was found standing erect, which was 20 ft. in length, and at the base measured 18 in. in diameter. The centre of the fossil was sandstone, and the outer portion consisted of carbonised wood.

Houston Coal.—A section in the West Calder Burn, south of Burngrange, shows that thin laminated sandstones with shale partings separate the Fells Shale and Houston Coal. A pit sunk to the oil-shale 25 yds. to the west of the coal crop reached the shale at 32 fms., and, allowing for dip and rise, the vertical distance between shale and coal is 150 ft.

On both sides of the Breich Water this coal was at one time extensively worked along its outcrop between the Blackbrae and Mid-Breich faults. Its general thickness was about six feet with

one foot of stone in the centre. At Gavieside the coal has the following section :—

	Ft.	In.
Roof, fireclay.		
Coal	0	6
Coal and blaes	0	4
Coal	0	7
Parting	0	0½
Coal	1	2
Mudstone	0	9
Coal	1	2½
Parting	0	1½
Coal	1	0½
	5	9
Pavement, fireclay.		

Grey Shale.—In the West Calder Burn 73 ft. of strata, composed of beds of sandstone with fireclay and shale partings accompanied by two thin coals, separate the Houston Coal from the Grey Shale. This bed, 1 ft. 8 in. thick, is almost entirely composed of entomostracan remains.

Houston Marls.—The Grey Shale forms the base of these marls, which vary in thickness from 104 to 230 ft. A section of these beds is exposed in the Breich Water above Breich Mill, and here the marls and blaes contain numerous seams of ironstone from 2 to 4 in. thick.

Two-Foot Coal.—Above the Houston Marls lies the Two-Foot Coal, with a sandstone roof and fireclay pavement, which has never been wrought in the West Calder district, but in a bore at Westwood it shows the following section :—

	Ft.	In.
Roof, sandstone.		
Coal, coarse splint	0	10
„ cherry	0	8
„ coarse	0	6
	2	0
Pavement, fireclay.		

Two feet appears to be its maximum thickness, for in the Breich Water it measures only seven inches, and is there covered by black shale with several seams of good clay-ironstone. Next in order comes a series of shales, fakes, and fireclays with a few thin beds of sandstone, and in the upper portion of this group there are numerous bands of ball ironstone with dark shales and fireclays. From the Blackbrae fault the outcrops of this seam and of the Houston Coal trend generally N.° 10° W., but to the S.S.W. of Mid-Breich a shallow synclinal fold carries both these outcrops for some distance to the south-west. The thickness of strata between the Two-Foot Coal and the Mungle Shale is estimated to range from 130 to 180 ft.

Mungle Shale.—This seam varies in thickness from 20 in. to 2 ft., and was worked by shallow pits on both sides of the Breich Water, near Addiewell. About 120 ft. of shale with ironstone

ribs, fakes, and fireclay lie between this seam and the Raeburn Shale.

Raeburn Shale.—In the early stage of the oil-shale industry in the Addiewell district the Raeburn Shale was known first as the "Dam Shale," and afterwards as the "Upper Shale of Addiewell." These are now correlated with the Raeburn Shale.

	Ft.	In.
Roof, blaes.		
Shale, curly	1	8
„ plain	0	9
Fireclay	0	3
Blaes	0	5
Shale	0	3
	3	4

Pavement, fireclay.

A section of this seam is given in the memoir on "The Oil-Shales of the Lothians," p. 24. The one above is from the same locality, and shows a slight difference in the sequence.

In the river Almond, on the west side of Hopefield Mills, a bed of ash lies a little above the Raeburn position.

The Raeburn Shale and the Hurlet Coal are separated at Addiewell by 75 fathoms of strata, which consist of shale with ironstone ribs, several thin coals, a freshwater limestone, and a few beds of sandstone, some of them coarse and pebbly. The freshwater limestone, which lies about 120 ft. below the Hurlet Coal, is exposed on the south bank of the Breich Water below Addiewell Bridge in two leaves, the largest not more than one foot thick, accompanied with coaly blaes. At South Cobbinshaw a bore close to the reservoir passes through two thin limestones and a coal, 150 ft. below the Hurlet Coal.

In the river Almond the strata between the Houston Coal and the Raeburn Shale are not seen east of the bridge south of Hopefield Cottage, and this gap is estimated to contain 430 ft. of strata. About 300 yds. west of this bridge, and about 100 ft. vertically below the Hurlet Limestone, there is a marine limestone, one foot thick, with abundant remains of encrinites, which is underlain by an inferior oil-shale with ironstone bands, and overlain by sandstones.

SHORE SECTION BETWEEN WHITEHOUSE POINT AND MIDHOPE BURN.

The coast section between Whitehouse Point and Midhope Burn at Abercorn is the best natural exposure of the oil-shale measures of the Lothians. It begins with strata 500 ft. below the Burdiehouse Limestone, and shows the sequence of the beds upwards to the base of the Broxburn Marls.

Between Whitehouse Point and Port Edgar there is a comparatively shallow basin two miles broad, in the centre of which the strata form a compound syncline with the Broxburn Marls as the highest beds. On the west limb of the compound fold South Queensferry is situated. From Springfield to Banks the strata fold over a very flat anticline, and near Society they pass into a deeper synclinal fold, which, for descriptive purposes, is called the Duddingston basin. West of this point is the well-marked Hopetoun anticline with its centre near Hopetoun House, whose eastern limb is steep, and

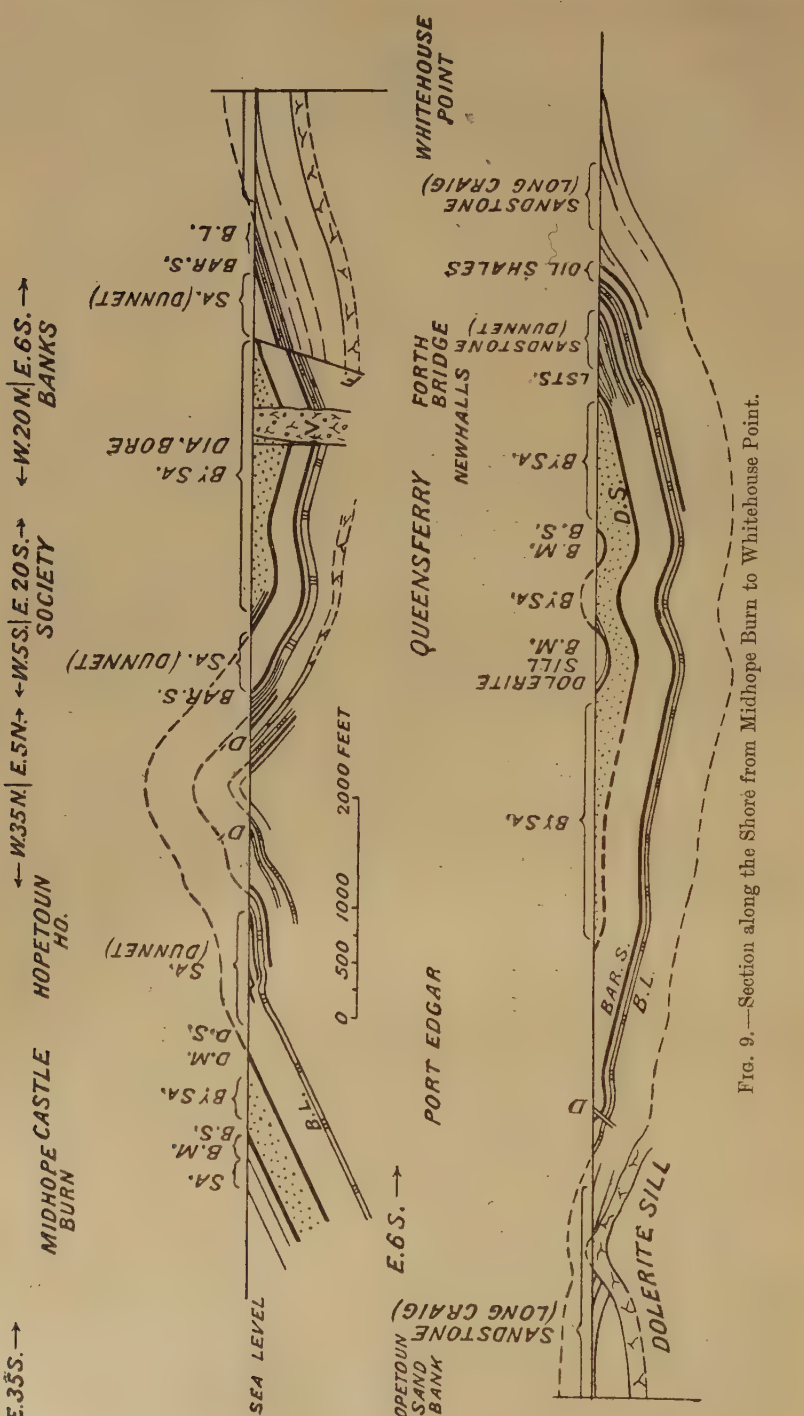

Fig. 9.—Section along the Shore from Midhope Burn to Whitehouse Point.

the western, after undulating gently for some distance, maintains a steady dip to the mouth of the Midhope Burn where the rock section terminates.

At Whitehouse Point the beds above the intrusive sill of Mons Hill are estimated to lie 555 ft. below the Burdiehouse Limestone. These consist of greenish grey shales, which, after a considerable gap, are succeeded by beds of sandstone, on one of which stands Long Craig Pier. Above these sandstones lies a band of oil-shale, 6 ft. thick, whose position is calculated to be 90 ft. below the Burdiehouse Limestone, which at this point forms the "Long Rib,"—a conspicuous reef on the shore section. Here it is a cream-coloured rock, 7 ft. 10 in. thick, with a thin parting of bituminous blaes, which dips to the west at an angle of 45°, but this high inclination is not maintained for any distance as the beds soon resume their normal dip of 15° to 20°. The Burdiehouse Limestone here rests on limy and bituminous blaes with a curly oil-shale of good quality, and in the past it was quarried both on the shore and at New Gardens. Next in order come bituminous and alum shales, 14½ ft. thick, followed by 11½ ft. of oil-shale. The top and bottom of this oil-seam are particularly rich, the upper portion containing strings and pieces of bitumen. It is succeeded by 78 ft. of black bituminous shales with thin limestone and ironstone bands overlain by an oil-shale, 8 ft. thick, with a calcareous roof. These two oil-shales above the Burdiehouse Limestone are of excellent quality and may be correlated with the Barracks Shale.

The upper oil-shale is surmounted by a thick sandstone series followed by three thin limestones associated with faky shales and bands.

Dunnet Shale.—This shale together with its characteristic marl appears immediately below the Forth Bridge, but the section is partly obscured by a small fault. It is computed to lie 341 ft. above the Burdiehouse Limestone.*

Binny Sandstone Series.—Above the Dunnet Shale come 300 ft. of brown, white and yellow sandstones — the local representatives of the Binny Sandstone series. On the west side of the Queensferry basin near Port Edgar these sandstones were at one time extensively quarried for rubble work, and, on the shore to the west of the town, an impure calcareous band about four feet thick forms part of this series. A similar band is found in the West Calder district at this horizon. As already mentioned a compound syncline occupies the centre of the Queensferry basin, and at the "The Craigs," midway between the pier and Newhalls, is situated the anticlinal axis which separates the two synclinal folds.

Broxburn Shale. — This shale rests on the Binny Sandstone series, and is exposed on the shore just below the east wall of Queensferry harbour, and also on the opposite side of the west synclinal fold near the church. Here it is 7½ ft. thick, but inland in the railway cutting it measures 9 ft.

Dunnet Shale.—This shale is not visible on the west side of the Queensferry basin, but it is probable that its outcrop lies on the west side of the slip pier inside Port Edgar, and runs south-east as indicated on the one-inch map.

* For details see Vertical Section, Whitehouse Point to South Queensferry, "The Oil-Shales of the Lothians," *Mem. Geol. Sur.*, p. 74.

Barracks Shale.—The railway section begins at Port Edgar about twenty feet above the Burdiehouse Limestone with bituminous shales intersected by a thin "white trap" dyke. These bituminous bands represent the position of the Barracks Shale, and are succeeded by black shales with thin limestones and ironstone nodules. Next in order comes a grey calcareous sandstone, 18 ft. thick, overlain by black shales with cement ribs. These beds above the sandstone dip north-east at an average angle of 14°, and in the cutting are 275 ft. thick, so that the Dunnet Shale position must lie a short distance to the east of this rock section.

A considerable difference is observable between the lithological characters of the strata on the west side of the Queensferry basin and those on the east side from the Forth Bridge to the "Long Rib." In the latter section nearly one-third of the sediments is siliceous while in the railway section the proportion is one-seventh, which clearly indicates shallow water conditions on the east side and deeper water sedimentation on the west.

Burdiehouse Limestone.—On the west side of Port Edgar is situated the outcrop of the Burdiehouse Limestone, formerly mined between the shore and Echline. These workings were known as the Dundas Limework, and the seam varied from six to nine feet, was dark in colour, and contained some iron. It formed three beds dipping to E.N.E., and was crossed by a dyke of so-called "sandstone conglomerate" divided in the centre by a vein of spar containing galena.

West of the outcrop of the Burdiehouse Limestone for about 200 yds. no rock is visible on the shore till sandstones with an easterly dip appear at the junction of the two roads. This gap is quite sufficient to contain the strata, together with the two oil-shales, which occur below the limestone on the east side of the Queensferry basin. The sandstones at the two roads overlie a dolerite sill of no great thickness, and dip first to east and then roll over at a gentle angle to the north-west. From the mouth of the Linn Mill Burn to a point south of the Hopetoun sandbank these sandstones, which are there about 200 ft. thick, form the eastern limb of the Duddingston basin, and they probably represent the beds at Long Craig Pier east of Queensferry. South of Hopetoun bank they are overlain with beds of bituminous shale and pass beneath the Burdiehouse Limestone.

Beyond these sandstones, on the shore north-east of Banks the Burdiehouse Limestone occurs in three leaves, is of the dark type and weathers with a bright yellow ochreous coating. Above the top bed there is a gap representing 8 ft. of vertical thickness, which has the appearance of being quarried, but, if limestone beds have not been removed, it may represent the position of the alum shale on the east side of the Queensferry basin. Above this gap comes the Barracks Shale consisting of 10½ ft. of mixed oil-shale and blaes. To the N.N.E. of Banks a calcareous sandstone crops out on the shore, and between this horizon and the Burdiehouse Limestone 225 ft. of strata occur, chiefly composed of beds of sandstone. At this point a small strike fault, with a displacement to the west, probably throws down the Dunnet Shale which will account for its absence in this part of the coast section.

Binny Sandstone Series.—Between the calcareous band N.N.E. of Banks and the west end of Society village, ripple-marked sandstones with carbonaceous streaks occupy the shore section. At first these beds dip west, but after minor undulations they incline in an easterly direction near Society. In this portion of the section they surround a small oval-shaped mass of a dark greenish felspathic agglomerate, which, from its mode of occurrence, probably represents an ash neck.

Dunnet Shale.—At Society the Dunnet Oil-shale lies at the base of the Binny Sandstone, where it is separated into two beds, each about 5 ft. thick. The lower of the two is of excellent quality and rests upon a black carbonaceous ironstone full of fish remains.

Dunnet Marls.—The top Dunnet Oil-shale has a calcareous roof covered by 22 ft. of shale succeeded by 30 ft. of marls with limestone bands—representing this horizon.

In 1901 the landward outcrop of the Dunnet Shale was proved by the Dalmeny Oil Co., and was found to follow very closely the old quarried outcrops of the Burdiehouse Limestone on the west side of the Duddingston basin. A diamond bore drilled to the north of Crawstone near the centre of this basin passed through the Binny Sandstone, and at 324 ft. proved the Dunnet Shale to be 12 ft. thick; it further proved at a depth of 570 ft. from the surface the Barracks Shale and the Burdiehouse Limestone below.* The Dunnet Shale on being tested yielded 27½ gallons of crude oil and fully 35 lb. of sulphate of ammonia per ton.

On the shore section already described, the beds which separate the Burdiehouse Limestone and the Dunnet Shale on the east side of the Duddingston basin are chiefly yellow and white sandstones estimated to be 225 ft. thick. But in the Crawstone diamond bore a great change takes place in the strata above the limestone. This bore is only 700 yds. from the shore, and its record shows that the sandstone beds are represented by limy fakes and blaes in the proportion of 1 to 5 in a total thickness of 221 ft.

The measured shore section on the west side of the Duddingston basin, and on the east limb of the Hopetoun anticline, extends 425 yds. to the west of Society and nearly reaches the centre of the Hopetoun arch.† On the shore the thickness of strata between the Dunnet Shale and the Burdiehouse Limestone is estimated at 343 ft. as compared with 221 ft. in the Crawstone bore. Here again there is a remarkable difference in the nature of the strata intervening between these two horizons. On the coast section three-fourths of the beds are composed of siliceous materials and the remaining portion of argillaceous sediments. In the Crawstone bore the proportion of these two types of deposit is reversed. This difference of sedimentation within so short a distance, when viewed in connection with the change already noted in the beds above the Burdiehouse Limestone at Port Edgar, is worthy of note, as it indicates a rapid alternation between shallow and deeper water conditions within a very limited area. These shore

* For details of section in the Crawstone diamond bore, see "The Oil-Shales of the Lothians," *Mem. Geol. Sur.*, p. 80.

† For details regarding the shore section on the east side of Hopetoun anticline, see *op. cit.* p. 81.

conditions are more highly developed to the north and east, and point to a limitation of the oil-shale deposits in these directions.

Towards the base of the sequence on the east side of the Hopetoun anticline there is an intrusive sill of white or yellowish igneous rock, 6 ft. thick, in two sheets with soft blaes between, which has cavities full of bitumen, like those noted in the Broxburn section. If this intrusive mass is the same as that exposed at the mouth of the Linn Mill Burn, it here occupies a slightly lower position. Below the sill on the Hopetoun shore we find about 50 ft. of shale, bituminous shales, and 8 ft. of a hard black limestone with worm tubes, which, when dissolved in hydrochloric acid, is found to be rich in lime. It evolves a considerable quantity of sulphuretted hydrogen gas, and leaves a fine black carbonaceous residue.

From Society village to a point above the black limestone all the strata dip steadily to east, but where this bed appears the direction of the dip changes slowly to west by north. Hence the axis of this fold is well defined.

The limestone charged with worm tubes lies 259 ft. below the Burdiehouse Limestone, and beneath it come shales with oil-shale and cement bands, which graduate downwards into shales with hard ironstone bands. These are the lowest beds exposed on the eastern limb of the Hopetoun anticline, and their position is calculated to be 342 ft. below the Burdiehouse Limestone.

On the west side of the Hopetoun anticline* and a short distance above the worm tube limestone, the sill with bitumen is seen resting on a few feet of oil-shale of inferior quality. For 100 yds. across the strike the shore is covered with mud, and the first beds seen are shales with bands of oil-shale and thin limestones. Calcareous shales with limy bands separate these from the Burdiehouse Limestone, 32 ft. thick, which has here a brecciated and flinty base, while its upper portion is a dark limestone full of plant and fish remains. Several minor folds carry the bed along the shore for 150 yds. just below high-water mark, where it resumes its normal strike and passes inland on the west side of Hopetoun House. Scattered heaps of debris on this part of the shore indicate where the Burdiehouse Limestone has been quarried, and beyond these heaps the Barracks Shale, 10 ft. thick, mixed with sandy shales, crops out on the shore. Westwards a good many gaps occur with sandstone beds at intervals till the Dunnet Shale is reached, which is well exposed on the shore to the E.N.E. of the old Castle of Abercorn. It is a rich band, 16 ft. thick, and contains plant remains.

Binny Sandstone.—Yellow and grey faky sandstones with several gaps represent the next 308 ft. of strata, and on a sandstone pavement rests the Broxburn oil-shale.

Broxburn Shale.—This seam, 16 ft. thick (with a thin cement parting), contains entomostraca together with abundant fish remains. The roof consists of a dark limestone, 1 ft. thick. Next in order come 60 ft. of calcareous and siliceous beds (with gaps) which probably represent the Broxburn marls. A succession of false-bedded, flaggy sandstones, 138 ft. thick, completes the section to the Midhope Burn.

J. S. G. W.

* For details regarding the shore section on the west side of the Hopetoun anticline, *op. cit.* p. 83.

DRUMCROSSHALL TO WESTER OCHILTREE.

From Drumcrosshall the crop of the Houston Coal trends in a north-easterly direction and, after being thrown by a fault towards the west near West Bangour, runs towards the north. In draining a field half a mile west of Blackcraig, the coal crop, together with the overlying Houston marls and Two-foot Coal, was found running obliquely up the slope of the hill in a N.N.E. direction. From here the crops, together with that of the ash above the Two-foot Coal, swing round to the east and then back again to N.N.E. just before they reach the Uphall fault. Beyond the fault the crop is shown by old workings as far as the Ecclesmachan fault, which throws the crop some distance to the west. The old crop workings are again seen in the neighbourhood of Wester Ochiltree.

An excellent section of the ash above the Two-foot Coal is exposed in the Brox Burn below the reservoir for the Bangour Asylum. The ash is succeeded by blaes with bands of bituminous shale and some sandstones. Above the latter there follow a green ash and then the basaltic lavas, which are a southward prolongation of the Riccarton Hills basalts. H. B. M.

WESTER OCHILTREE AND KINGSCAVIL DISTRICT.

The Fells oil-shale is not seen to the west of Wester Ochiltree but it probably occurs on both sides of an anticline that repeats the Houston Coal, a seam which was formerly worked in a basin to the east of Wester Ochiltree, but details of the old workings are not available. Towards the west the outcrop of this coal is fairly well defined by old crop workings; it runs through a plantation 540 yds. W.S.W. of Wester Ochiltree and can be traced running slightly east of north as far as the Haugh Burn alluvium, after which it is not seen again south of Kingscavil.

On the east bank of a stream south of the road, half a mile west of Wester Ochiltree, the Two-foot Coal was sought in a trial hole. On the west bank a low cliff shows several feet of dark carbonaceous shales containing cyprids and coprolites of *Rhizodus* (?). At the junction between these shales and the bed of ash above, there is a good deal of disturbance, as is usual near boundaries of different texture. The thickness of this ash is not less than 50 ft. Search has evidently been made for the Two-foot Coal below, but with what success we do not know. The tuff can be traced northward to the Haugh Burn, being seen 600 yds. east of Riccarton, whilst another trial hole to the coal is seen close by; the outcrop then swings round, bearing N.N.E. and is seen once more in a stream passing through a wood 450 yds. south of Haugh Burn; some oil-shales farther down this stream may occupy the position of one of the upper seams.

North of Haugh Burn, neither shales nor coals are recognised, and a large fault proved in the Champfleurie workings perhaps traverses part of this ground and shifts the outcrops to the east on its northern side.

At Kingscavil Quarry—in beds lying between the Two-foot Coal

and the base of the Carboniferous Limestone series—the following section is seen :—

	Ft.	In.
Boulder clay		
Broken sandstone	6	0
Dark shales with septaria	15	0
Sandstone, flaggy at base	11	6
Blue shale	1	0
Coal	0	6
Sandstone, main bed	50	0
Sandy shales	5	0

North of Park some borings were made in 1897 in search of this sandstone, and another of earlier date in the same locality passed through a bed of sandstone 76 ft. thick, but with too many thin partings to be workable. Above this, a coal is said to have been found while making the foundations of the canal bridge. The strata between the Houston Coal and the limestone at Carsie Hill *—which is taken as the base of the Carboniferous Limestone series—appear to be mainly arenaceous, but some thin bands of limestone also occur, the chief of which is exposed 400 yds. up the Riccarton Burn, and consists of a thin lower bed and an upper one, $3\frac{1}{2}$ ft. thick, separated by an obscure interval in which there is room for 5 or 6 ft. of strata which are not seen. Brachiopods occur in the upper bed. Fragments of a similar limestone were obtained from an excavation at Riccarton, but we are not justified in supposing this bed to be the limestone which occurs in the stream, repeated by faulting and folding. Calcareous bands occur among the sediments seen in the vicinity of the necks 900 yds. slightly east of north from Riccarton.

It is on this calcareous horizon that the first lavas (Longmuir Plantation group) are seen 800 yds. south of Riccarton, and above these, in the stream 200 yds. south-west of the road, a remarkable breccia of siliceous character is found; the fragments are angular and are either hard and sandy, or soft—the latter may be white trap. This breccia may possibly have some connection with the early eruptions or it may be a crush breccia belonging to some fault of small size.

Of the rocks between the northward prolongation of the Riccarton Hills lavas and the line chosen as the base of the Carboniferous Limestone series, we have little evidence; 300 yds. south of Whitebaulks a sandstone is seen on the road, and it is stated that coal has been obtained in small quantities near this spot. This appears to be the seam underlying the limestone at Whitebaulks.

G. W. G.

BLACKNESS AND KINGSFIELD AREA.

In this area, extending along the south side of the Forth from Blackness westward to the neighbourhood of Stacks and inland to Kingsfield, no rocks are exposed except along the shore on the west side of Blackness Bay, in small outcrops on the present beach. Among them is a limestone, compact and creamy with occasional pink blotches, which weathers into small knobs and seems to be about two feet thick; it appears to contain no fossil remains except some obscure rootlets, and is perhaps of fresh-water or estuarine

* Carsie Hill is not marked on Sheet 32; it lies 380 yds. east of Cauldhame.

origin. It somewhat resembles the limestone at the Limekilns Golf Course, on the north side of the Forth, which is estimated by Mr. Maufe to be perhaps 160 ft. below the bed taken as the base of the Carboniferous Limestone series in that locality. Both a little above and a little below the Blackness Limestone soft yellow false-bedded sandstones occur; the lower is probably at least 40 ft. thick and is underlain by dark grey shales and flaggy sandstones.

The beds described have a north-easterly dip, but, a little distance west of the exposures, they probably roll over and dip north-west beneath the beds referred to the Carboniferous Limestone series.

A boring, the position of which is supposed to be about a quarter of a mile S.S.E. of Cauldcoats, pierced an impure limestone which may possibly represent the Blackness bed. It is 3 ft. 5 in. thick, including a shale parting in the middle, and was met at a depth of 26 fms. from the rock surface.

The journal of another bore, the position of which is about 400 yds. W.S.W. of Merrylees, records a depth of more than 49 fms., and a considerable thickness of marls which may be the Houston marls. The rocks first met with probably belong to a position considerably below the Blackness Limestone. They consist of sandstones and fakes, together more than 14 fms. thick, and may possibly represent the thick sandstone quarried near Pardovan.

C. T. C.

CHAPTER IX.

CARBONIFEROUS LIMESTONE SERIES OF THE COBBINSHAW, BATHGATE, BO'NESS AND CHARLESTOWN DISTRICT.

This district comprises a narrow belt of country extending from Cobbinshaw and Addiewell in the south to Bo'ness and Carriden in the north, together with a small area on the north side of the Firth of Forth at Charlestown and Limekilns. The portion of the county of Fife that projects southwards into Sheet 32 was not included in the scheme of revision of the Carboniferous Rocks of the Lothians, as the geology of that area was described by Sir A. Geikie in the memoir on Central and Western Fife. But the adoption of the West Kirkton and Tartraven Limestone as the representative of the Hurlet Limestone necessitated the re-examination of the shore section west of Rosyth where the Petershill Limestone had been mapped as the basal member of the Carboniferous Limestone series.*

The three groups of the Carboniferous Limestone series, together with various details regarding their development in this district, are given in the subjoined table—

3. Upper Limestone group, with three or four thin marine limestones and some thin coals. Near the Forth it appears to be more than 800 ft. thick, but farther south it becomes much thinner. At Hilderston, rather more than three miles north of Bathgate, it is only 446 ft., even with the inclusion of a considerable thickness of igneous rock.
2. Bo'ness and Bathgate Coal group. A thick series of sandstones and shales with valuable coals corresponding to the Edge Coals of Mid-Lothian. The thickness, including volcanic rocks, near the Forth, amounts perhaps to 950 ft. At and a little south of Bathgate, in an area where the volcanic rocks are not quite so well developed as near the Forth, the thickness is about 750 ft.
1. Lower Limestone group, with various marine limestones, some of which are of considerable thickness. In the Bathgate Hills, where the volcanic rocks are strongly developed, the thickness is perhaps nearly 1000 ft. Near the Forth the group is almost free from volcanic rocks, and its thickness is probably not much more than half this amount. In the Cobbinshaw and Addiewell district, also, it cannot much exceed 500 ft.

The character of the series as a whole differs remarkably from that in Mid-Lothian owing to the intercalation of great thicknesses of igneous rock with the sediments. Near Linlithgow, and for four or five miles to the south the igneous rocks are so largely developed that the Bo'ness and Bathgate Coal group is of little or no economic value.

We shall now proceed to describe the different rock-groups in detail, taking first the Lower Limestone division, and advancing from

* "The Geology of Central and Western Fife and Kinross," *Mem. Geol. Sur.*, 1900, p. 89.

south to north through the different areas in which the district has been divided for descriptive purposes. C. T. C.

Lower Limestone Group.

Cobbinshaw and Addiewell Area (Sheet 31 in part).

The Cobbinshaw-Hurlet Limestone enters Sheet 32 at the south end of Cobbinshaw Reservoir. Immediately below the limestone lies the Cobbinshaw Coal,* which has been wrought over this portion of the field from Viewfield coal pit, situated just outside the limits of the Sheet. In this working the limestone formed the roof, and the section was as follows:—

	Ft.	In.
Blaes		
Limestone	2	0
Black blaes	2	6
Coal	3	9
Pavement—blaes		

A little to the south-west of Cobbinshaw Station both limestone and coal are wrought by means of a mine, and both are thicker than at Viewfield, as shown in the subjoined section:—

	Ft.	In.
Roof—shale	0	7
Limestone	5	6
Blaes	3	0
Coal	4	0
Pavement—fireclay	0	9
	13	10

At this mine the coal is first taken out, and on removing the props the overlying blaes and limestone fall down. At the base of the coal there are lines of brassy balls which consist of very fine casts of *Bellerophon* in iron pyrites. The blaes is aluminous and contains a "brown stone," composed partly of parrot coal, and partly of ironstone. The limestone is a dark-grey encrinital bed, very fossiliferous and weathers with a brown crust. It is burnt in draw-kilns close to the mine mouth. The greater part of the coal, which is of inferior quality, is used for lime-burning and the surplus is sold as fuel. A little distance to the west of Cobbinshaw Station, the coal was reached by a pit 22 fms. deep, and to the north of this locality the Pearie Law fault brings up the underlying Oil-shale group. The effect of this fracture combined with the Murieston fault is to shift the outcrops of the limestone and coal to within half a mile of Baad's Mill. A short distance above the mill, on the side of the Harwood Water, an old quarry with the remains of a kiln indicates that the limestone was quarried and burnt with its coal at this point. Lower down the stream a thin rough coal crops out 150 ft. below the limestone. From Baad's Mill the limestone appears to pass by the east of Townhead (Sheet 31) to the Longhill Burn, where there are several quarries now grassed over. On the north side of this stream the

* As this limestone is taken as the bottom bed of the Carboniferous Limestone series, the underlying coal ought strictly to be described with the Calciferous Sandstone series, but it has so often to be mentioned in connection with the limestone that it is best to describe the two together.

outcrop is interrupted by several faults, but, from the west side of Addiewell Chemical Works to Addiewell Bridge, the position of the limestone is again indicated by a chain of abandoned quarries. On the south side of Addiewell Bridge the limestone and coal were wrought together opencast and afterwards by shallow pits, which gave the following section:—

	Ft.	In.
Limestone	4	0
Blaes	1	6
Coal	5	6

In the Breich Water just above the bridge the outcrop of the limestone is repeated by a small fault. Between Addiewell Bridge and Blackburn Hall, the limestone has not been wrought, but the underlying coal has been opened out to the north of Cuthill and found to be four feet thick.

Several limestones occur above the Cobbinshaw-Hurlet Limestone in the burn opposite the shooting lodge on Pates Hill; two of which are thin, weather with a calmy yellow crust, and are separated by 18 ft. of black shale with ironstone nodules. The lowest band is one foot thick and the upper, four to five feet, and, when fresh, each is a solid blue-black limestone. These limestones are estimated to lie about 450 ft. above the Cobbinshaw-Hurlet Limestone. A short distance up this stream there are old limestone quarries all grassed over.

On the south side of the large east and west fault that crosses Leven Seat (one-inch map 31), one of the last-mentioned limestones is exposed along the crest of an anticlinal fold, and is in two leaves. On the east and west sides of the plication two small streams show that about 190 ft. of black shale separate this limestone from two higher ones. In the middle of this shale lies a rough ironstone which has been wrought opencast. The two higher limestones appear on the east side of the arch, about a mile and a quarter from the south-west corner of Sheet 32.

The best section of the Lower Limestone group is exposed in the Breich Water. Here the beds overlying the Cobbinshaw-Hurlet Limestone are shales and soft flaggy sandstones with two coal seams one of which has been wrought. About thirty feet above the highest of these seams a grassy hollow with limestone fragments marks the position of the first limestone above the Cobbinshaw-Hurlet. The interval between this old quarry and the intrusive sill shown on the map is occupied with bands of shale and faky sandstone. The section in the main stream ceases with the igneous intrusion but is continued in the Skolie Burn, at the mouth of which, and for some distance to the south, two bands of limestone, one foot and five feet thick respectively, and separated by nine feet of fossiliferous shale, all dipping to west, are well exposed. These limestones are estimated to lie about 425 ft. above the Cobbinshaw-Hurlet, and are probably the northern extension of the bands at Pates Hill. They are succeeded by blue-black shales overlain by a dark limestone with a very fossiliferous shale. Above the limestone comes a considerable thickness of blue-black shale with a nodular fireclay, on top of which is a dark limestone, 2 ft. 10 in. thick. It seems probable that all these limestones above the Cobbinshaw-Hurlet correspond to the Hosie Limestones of Fife. The estimated distance between the top of the

highest of these Skolie Burn limestones and the base of the Cobbinshaw Limestone is about 520 ft. J. S. G. W.

BATHGATE AREA (Sheet 31).

The next section to the north of the Breich Water (Sheet 31) is furnished by the Almond, and presents a sequence agreeing exactly with that occurring to the south. It affords no evidence of a transition towards the abnormal development which characterises the group only one or two miles farther north, in the volcanic district of the Bathgate Hills.

In the description of the Calciferous Sandstone series (p. 95), mention has already been made of an encrinital limestone, one foot thick, which is exposed in the Almond, 300 yds. above Hopefield Mills. The section above this limestone is incomplete, but there is room for several hundred feet of strata between it and the Cobbinshaw-Hurlet band, the latter being well exposed in the bed of the stream, where it is an encrinital limestone similar to that of the Breich Water. The underlying coal is not exposed in the burn, but the following section is taken from the Redhouse Colliery situated a little to the north:—

	Ft.
Limestone	8
Parrot Coal	8 in.
Free Coal	8 in. } 2
Gas Coal and ironstone balls	8 in.
Cement and ferruginous limestone	3
Shaly sandstone	10
Coal	4
Wild Gas Coal	2
Hard brown sandstone	

The section of the strata overlying this limestone in the stream is not continuous, but for some distance it shows black shales and faky sandstones: about 150 ft. above the limestone a thin impersistent encrinital bed has also been recognised resting upon some faky sandstones interbedded between two thick black shales. Higher up the burn a massive sandstone is exposed, a little below which a coal was worked at the outcrop on the northern bank. This sandstone and coal have also been recognised in the Breich Water to the south. Almost directly above the sandstone comes a bed of encrinital limestone, about eight feet thick, which closely resembles the Cobbinshaw-Hurlet, but probably lies about 300 ft. above it. It has been wrought on both sides of the stream, and is underlain by a thin coal.* The exposure of this limestone in the Almond serves to supplement the Breich section, for in the latter the position is only indicated by an old quarry now completely grassed over.

At the present time there is no exposure in the stream to the west of this limestone, but Sir A. Geikie mapped another thin band of encrinital limestone, 1½ ft. thick, which was exposed just to the east of the "leckstone" quarry, and underlain by a coal eight or nine inches thick. Moreover, a few bores put down in this locality indicate the presence of at least another limestone, 8 ft. thick, which probably crosses the

* "The Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861, p. 55.

stream a little west of Blackburn Bridge. A blackband ironstone about a foot thick is recorded in the same bores about 27 fms. beneath this limestone. There can be no question that these upper beds belong to the group, already described, as occurring in the Skolie Burn, the small tributary that joins the Breich Water near Addiewell. No contemporaneous volcanic rocks are known in the Lower Limestone group of the Almond section. The "leckstone" or picrite of Blackburn was formerly described as a lava flow,* but it must no doubt be classed with the picrite of Breich Water, which is now held to be an intrusion (p. 281).

Between the Almond section and the Bathgate Hills the country is covered with deep boulder clay, wide stretches of peat, and other superficial deposits. In the first sections in the hill country, some two miles north of the Almond, the beds of the Lower Limestone group are so different from those just described that any correlation of individual bands in the two areas can only be advanced with considerable hesitation. Before attempting this correlation it will be advantageous to refer to the northern succession.

In the West Kirkton Quarry, a mile to the east of Bathgate, a marine limestone is exposed, the upper portion of which is interleaved with beds of volcanic ash.†

The following section was recorded at the time of the original Survey: ‡—

Dark basalt (diabase).
Limestone, with thin layers of green tuff.
Limestone in thick beds; containing encrinites, *Productus*, etc.
Thin shale.
Green tuff.
Limestone, ashy, and especially fossiliferous at the top, more shaly at bottom.
Dirty green, fine-grained, well-bedded tuff, containing a thin bed or vein of basalt 3 in. thick, and resting on a basalt sheet.

The upper ashy portion is about 15 ft. thick, and the limestone proper, fully 10 ft. Large chert nodules occur sparingly in the limestone. The physical conditions indicated by these deposits contrast strongly with those shown by the underlying beds of the East Kirkton Quarry, to be described later in connection with the volcanic group. In the west quarry "we see still the same evidences of the ejection of volcanic dust after the eruption of the basalt, but in place of the remains of land plants, we have now abundant traces of marine life, *producti*, *spirifers*, crinoids and corals; showing that the area had undergone a submergence below the sea. The siliceous matter occurs but sparingly, although there is still abundant evidence of volcanic action, the shells and zoophytes appearing not infrequently to have been destroyed by being enveloped in a thickening deposit of ash." §

The West Kirkton Limestone has been correlated with the

* Explanation of Sheet 31, *Mem. Geol. Sur.*, 1879, p. 24, and Sir A. Geikie's "Ancient Volcanoes of Great Britain," 1897, vol. i. p. 419.

† Probably the first good account of the section was that given by Hay Cunningham in his "Geology of the Lothians," 1838, p. 106, plate xii. fig. 3.

‡ Explanation of Sheet 31, *Mem. Geol. Sur.*, 1879, p. 19. The brackets in which diabase is inserted appear in the original.

§ "The Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861, p. 51.

Tartraven Limestone, which occurs farther to the north, and this correlation seems well founded, being based upon the similar stratigraphical position of the two with reference to the overlying Petershill Limestone. The latter is an excellent horizon, and has furnished invaluable assistance in unravelling the structure of the volcanic range, for it has been opened up in a series of quarries which extend without much interruption for about five miles. At West Kirkton the thickness of strata, including lavas, between the two limestones may be estimated at somewhat over 300 ft. The lower two-thirds of this sequence is composed mainly of basalt, and the upper third, of sedimentary strata, the bottom 50 ft. consisting chiefly of sandstone, as shown in a bore, the journal of which has been communicated by the Bathgate Borough Council. To the north of the road that crosses the Petershill Quarries additional lava streams occur, and for some distance occupy the position of the sedimentary strata just referred to, but, at the Knock, sandstones reappear underneath the Petershill Limestone and separated from it merely by a thin bed of ash.

The Petershill Limestone, being a thick bed, long worked and richly fossiliferous, has been known since the earliest days of geology, and is still a favourite collecting ground. The full thickness is not exposed in any of the Petershill Quarries but it was formerly * estimated at about 70 or 80 ft. Its lowest portion is well seen in the Bathgate Reservoir just north of the Petershill road, and is remarkable for the abundance and good preservation of its fossils. Bands of different palæontological character may be recognised, some consisting almost entirely of *Lithostrotion*, others of large cup corals, others again of *Productus giganteus*, while more shaly layers are distinguished by the abundance of *Pterinopecten* and other mud-frequenting forms. The main mass of the limestone is less fossiliferous, but towards the top a zone rich in *Productus giganteus* and another with abundant encrinites may frequently be noted. A characteristic of one of the upper zones is the frequent occurrence of chert in large irregularly shaped masses, within which the more or less silicified remains of encrinites and other originally calcareous forms can be readily recognised. Dr. Crampton suggests that the silica may have been derived from sponge skeletons, which form an important though rather inconspicuous element in the composition of the limestone.

In the Gallabraes Quarry, a little to the north, a persistent bed of white sandstone rests directly on the limestone and is surmounted in turn by a thick black shale. Farther north, before reaching the Knock, and just south of where an east and west dolerite dyke crosses the line of quarries, the sandstone extends into a curious cavity in the limestone, and, till examined closely, presents the appearance of a lenticular sill of "white trap." The same thin bed of sandstone may be followed through the Silvermine Quarries to the north and reappears at Hillhouse.

In the district of West Kirkton and Petershill it is impossible to draw a line between the Lower Limestone group and the Bo'ness and Bathgate Coal group. A great mass of basaltic lavas occurs about this position, and the few intercalations of sedimentary material exposed are devoid of special interest.

* *Op. cit.* p. 54.

Limestones that come above the Petershill bed, which also belong to the Lower Limestone group, are known, however, to the north, at Wairdlaw and Carriden,* and two thin limestones apparently on a similar horizon have recently been proved in a bore situated a mile to the south of Bathgate, which gave the following section: † —

	Fms.	Ft.	In.
Main Coal	0	5	1
Strata with some igneous rocks	87	0	7
Limy blaes with shells	0	0	11
Limestone	0	2	6
Blaes	0	0	11
Coal	0	0	2
Sandstone	0	1	6
Faky blaes	0	0	6
Sandstone	2	3	11
Faky sandstone	1	1	2
Blaes	0	0	4
Fakes and blaes	1	4	10
Blaes and ribs	4	2	6
Blaes and balls	1	0	2
Ironstone ball	0	0	1
Blaes and ribs	0	5	0
Blaes with shells	0	1	3
Limestone	0	2	11
Blaes	0	1	11
Blaes and ironstone ribs	0	2	8
Sandstone	0	0	5

The Main Coal referred to in the above section is a well-known member of the Bathgate Coal group, and has been followed to the north, where it overlies the mass of volcanic rocks with which the Petershill Limestone is interbedded. The two thin limestones of the bore can scarcely be regarded as representatives of the latter limestone, and it seems extremely probable that they overlie it. The cores on examination showed the limestones to be dark and shaly, rich in marine lamellibranchs and resembling those of Skolie Burn. It is clear, in fact, that the limestones of the bore belong to the Skolie Burn group, recognisable to the north again at Carriden, and upon this basis we may again attempt the difficult task of correlating the Cobbinshaw-Hurlet band with one or other of the Bathgate Limestones. The view originally expressed by Sir A. Geikie ‡ was that the West Kirkton Limestone probably represents the Cobbinshaw-Hurlet Limestone, and that the Petershill Limestone is the continuation of the 8-ft. limestone exposed in the Almond section about 300 ft. above the latter. In later publications he abandoned this view and correlated the Petershill with the Hurlet Limestone. Mr. Cadell § has, however, returned to the earlier interpretation, which, for the following reasons, has been adopted in this memoir. It is assumed that the limestones in the bore a mile south of Bathgate are equivalent to the upper or Skolie Burn group of limestones of the Breich and Almond. Beneath this upper group, two specially

* See pp. 111 and 113 of this memoir.

† Communicated by Messrs. Gavin Paul & Co. The thicknesses given have been corrected for a dip of 25°.

‡ "The Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861, pp. 53 and 55.

§ "Carboniferous Limestone Coal-Fields of West Lothian," *Trans. Inst. Min. Engrs.*, 1901, plate x.

important beds of marine limestone occur in the Bathgate Hills and in the Blackburn-Cobbinshaw District, namely, the Petershill and West Kirkton Limestones in the former, and an unnamed limestone, together with the Cobbinshaw-Hurlet, in the latter. In both areas the interval between the two limestones mentioned is about 300 ft., and it seems reasonable to correlate the one pair with the other. This leads back to Sir A. Geikie's original view that the West Kirkton band is the Hurlet Limestone of Cobbinshaw, and that the Petershill bed is the unnamed limestone of the Almond section.* E. B. B.

TARTRAVEN TO HILLHOUSE.

Northward from West Kirkton, the lowest limestone is exposed in a very poor section at Tartraven. Nothing is seen of the coal said to exist below, and the blaes above is quickly succeeded by a basalt. Beyond Tartraven the crop of the limestone is obscured by drift until the quarry at Whitebaulks is reached.

The limestone exposed in the quarries at the Silvermine (Sheet 31) is obviously a continuation of the Petershill Limestone, and is overlain by a similar series of sediments. Immediately above the limestone comes a thin bed of sandstone succeeded by a thick series of blaes, which pass up through faky beds into sandstone. In the North Mine Quarry the beds above the limestone are different. Resting on the limestone is a bed of fireclay with a layer of flattened casts of *Stigmaria* on its upper surface. Next follows a grey micaceous sandstone overlain by a blue and green ash and some blaes, the latter being in turn covered by basalt. The limestone probably passes through the swampy hollow running northwards from the quarries, but it is not again seen at the surface before the Hillhouse Quarries are reached.

At Wairdlaw, on the summit ridge of the Bathgate Hills, we meet with a local lenticular limestone higher than the Petershill Limestone. Whilst its horizon is evidently that of the Carriden and Skolie Burn Limestones, its peculiar character and position amidst basaltic lavas prevent an exact correlation being made. In the abundance of *Lithostrotion irregulare*, the close-set stems of which constitute entire layers of the rock, it differs from every other limestone of the district, except the Lower Kinning Point Limestone of the Charlestown district, which is also characterised by bands of *Lithostrotion*. The following section is seen in the quarry at Wairdlaw :—

	Ft.	In.
Platy basalt		
Blue blaes, dark and compact above, with *Calamites*, *Productus* and scales of *Palæoniscus*	4	6
Limestone with some pyrites	1	6
Dark blaes	0	9
Impure shaly limestone	1	6
Rib of hard compact shale with crinoids	1	9
Limestone with shaly partings and band of *Lithostrotion* ..	4	0
Black blaes	0	3
Limestone with *Lithostrotion*	3	6
Amygdaloidal basalt		

H. B. M.

* For further evidence upon this question see the description of the Lower Limestone group in the south-west of Fifeshire (p. 116 of this memoir).

HILLHOUSE TO LINLITHGOW.

The lowest limestone of the series is that formerly worked at Whitebaulks; it is about ten or twelve feet thick, of a compact bluish-grey texture with abundant fragments of small encrinites, and rests on a seam of coal from eight to ten inches thick. Farther north, it is seen dipping steeply to the west on the top and south side of Carsie Hill,* where it is a rusty crinoidal bed, 13 ft. thick, the colour of which is due to weathering of chalybite; when tested with hydrochloric acid it gives a yellowish liquid showing the presence of iron in fair quantity; the residue from solution is largely carbonaceous with a little heavier matter. Some of this carbonaceous residue is seen under the microscope to consist of minute spheres about $\frac{1}{4000}$ in. in diameter, which may be spores of some Carboniferous cryptogam. The structure of the ground in which this limestone occurs is difficult to understand, as only 150 yds. to the east a bed of limestone is again seen on the north side of the ridge dipping gently to the east and overlain by cherts, which are also seen on this slope about 100 yds. farther west. A small mound isolated by the alluvium, 200 yds. north of this ridge, shows pieces of shale and sandstone and small fragments of chert, but whether these are close to their source it is impossible to say; in fact, north of Carsie Hill we have no evidence on this horizon. At Whitebaulks the limestone is overlain by a black shale which is seen also above the bed at Carsie Hill.

In a quarry on the south side of the road at Cauldhame a bed of sandstone, over 50 ft. thick, is exposed without reaching the base, and above it, some sandy shales; this bed may be the upper part of that once worked at Porterside and seen on the ridge east of Cauldhame, where it occupies most of the ground between the limestone and the neck.

A bed of ash exposed on the road at Whitebaulks marks the base of the largest series of eruptive rocks in the area. It continues northward as far as Hillhouse, a little beyond which it ceases to be distinctly traceable.

The Hillhouse Limestone is exposed west of the farms of Hillhouse and Whitebaulks in a long series of quarries, trending S.S.W. for nearly half a mile, in which it has been extensively worked, but is now no longer used. The beds exposed vary in detail from point to point, but the section immediately south of the road a quarter of a mile north-west of Whitebaulks may be given as a type, and is as follows:—

	Ft.	In.
Columnar basalt, intrusive		
Sandy shale	0	6
Coal	0	6
Sandstone	3	6
Sandy shale	5	0
Dark shale	1	9
Sandstone	1	0
Ash	1	0

* Carsie Hill is not marked on Sheet 32; it lies 380 yds. east of Cauldhame.

	Ft.	In.
Sandstone	2	0
Sandy shale	5	0
Dark shale	1	0
Light clay	1	0
LIMESTONE		

The whole thickness of the limestone is not seen, but a section formerly exposed at the north end of the quarries is said to have shown 30 ft. of limestone and some shale below. The journal of a bore, put down a little way north of the locality where the limestone is last seen south of Hiltly, records 6 ft. of shale resting on 4 ft. of limestone. This shale may be that below the limestone, just referred to; so that the total thickness of the limestone, including the shale associated with it, may be 40 ft.

The limestone itself varies from band to band, being in parts crinoidal, while in others it is richly coralline, containing both solitary and colonial coral forms with occasional *Productus* and other brachiopods. It hardly seems possible that such a thick bed of limestone can exist farther north, for, in spite of the numerous exposures around Hiltly, which reveal a complex assemblage of basalts and fragmental rocks, there is no evidence of any limestone. A boring was made 350 yds. W.S.W. of the Manse, the journal of which has been lost, but Mr. Wylie, the borer, states that it was 130 fms. deep and pierced a thick bed of limestone near the bottom. During the making of the foundations for the Hospital west of Linlithgow Poorhouse, a band of crinoidal limestone, about four feet thick, was noticed by Mr. Cadell, which seems to be the limestone passed through in the well at the St. Magdalene Distillery at a depth of 66 ft., as a dip of 10° was found in the strata still exposed near the Hospital. Should this dip continue, a thick limestone lower down the well should crop out about a third of a mile east of Clarendon House, where its hypothetical position is shown on the map. This thick limestone is 220 ft. below the upper one, and it may occupy the position of the Hillhouse bed.

G. W. G.

LINLITHGOW TO CARRIDEN.

The total thickness of the Lower Limestone group in this area is perhaps 500 or 600 ft., but our knowledge of the lower strata is exceedingly slight. Three limestones belonging to the group are seen on or near the coast near Carriden: others in lower positions are recorded in bore journals but never exposed in this district. The highest of those visible on the shore is taken as the top bed of the Lower Limestone group, and has long been known as the Carriden Limestone. In this memoir it will be referred to as the Carriden Upper Limestone, to distinguish it from the other two, which will be termed the Carriden Middle and Lower Limestones.

Part of the Carriden Lower Limestone is seen on the shore a few feet below the Carriden Volcanic Ash, about 300 yds. E.N.E. of Carriden House: this horizon is only a little above the lowest beds of the Lower Limestone group which are visible in this area. The basal band, a hard calcareous sandstone with markings of *Cauda-galli*, is overlain by six or seven inches of shaly crinoidal limestone, above

which comes an obscure space in which additional calcareous bands probably occur; but the whole bed cannot exceed three or four feet in thickness, as it must pass beneath the position of a thin coal seam that was formerly exposed on the shore not far above the calcareous sandstone.

In a boring near No. 9 Pit, Grange, the section of the limestone and of the two calcareous bands below is recorded as follows:—

	Ft.	In.
Limestone	3	4
Black blaes	2	9
Limestone	0	2
Dark fireclay	1	7
Limy fakes	2	5

In a boring 100 yds. east of Carriden Church—usually termed the Cuffabouts boring—the sequence recorded is somewhat similar, namely:—

	Ft.	In.
Limestone	3	1
Black blaes	2	3
Limestone	0	4

From the above and other borings it is clear that at a depth of about 200 ft. below the Smithy Coal there is an horizon, sometimes more than 60 ft. thick, which contains several thin bands of limestone separated by various sediments. It is probable that the Carriden Lower Limestone forms the top of the calcareous horizon, and that other limestones, not exposed in this area, occur a little distance below it. The only beds seen at Carriden below this limestone are sandstones with a parting containing a coal five or six inches thick. The section somewhat resembles that in the railway cutting west of Charlestown, where a limestone crops out between a bed of ash and a coal with a fireclay seat. This limestone in the cutting is supposed by Mr. Maufe to be about 160 ft. above the thick Charlestown Limestone, and it is therefore doubtful whether any of the bores at Bridgeness went deep enough to reach the position of the latter, though the bore at Springfield, the journal of the lower part of which has been lost, may have done so.

The thin coal under the Carriden Lower Limestone on the shore is represented by a thicker seam in the Cuffabouts bore, where it is composed of an upper part of strong coal, 18 in. thick, and an under part of strong coal, 7 in. thick, with a one-inch parting of fireclay between the two. In the bore near No. 9 Pit, Grange, on the other hand, this coal appears to be represented by 25 in. of coaly blaes merely.

Carriden Pit bore No. 1, on the foreshore about 516 yds. N.E. by E. of Carriden Church, is supposed to have crossed, at a depth of 118 ft., an important fault—perhaps the east and west fault with considerable downthrow to the north, which passes a little south of Bridgeness. After crossing the supposed fault, the bore pierced a two-foot coal, at a depth of 260 ft., and it seems probable that it is in the position of the coal just alluded to in the Cuffabouts bore. About 59 ft. below this seam the bore entered calcareous beds and limestones which were proved to be more than 11 ft. thick without reaching the base.

At Carriden, the ash that comes above the little coal overlying the Carriden Lower Limestone is probably 40 or 50 ft. thick, and in Carriden Glen it is overlain directly by the Carriden Middle Limestone, which also seems to contain some ashy material. This limestone is crinoidal in the centre but only about 18 in. thick, and it is not clear that it is represented in the adjacent bores.

Above the Carriden Middle Limestone in the glen come 12 or 14 feet of shale, followed by about 40 ft. of flaggy sandstone with thin shaly partings, succeeded in turn by the Carriden Upper Limestone, which in this locality seems only a foot thick. A better exposure of this upper band is to be found in the old sandstone quarry a quarter of a mile east of Carriden Church, where it is a foot and a half thick, and rests on two feet of sandy clay. It weathers with a yellow colour and contains some crinoid joints, but is not rich in fossils. It seems to increase in thickness in a west or north-west direction, for in the Cuffabouts bore it is stated to be 2 ft. 7 in. thick, including a three-inch shale band, and in the bore near No. 9 Pit, Grange, it is 4 ft. 2 in., including a three-inch parting. In the last bore the limestone is 90 ft. below the Smithy Coal.

Inland south of Carriden the only satisfactory information obtained concerning this group is provided by a few bores. There is no evidence that the Carriden Upper Limestone exists in this landward area, and it seems probable that both it and the sediments, which at Carriden come between it and the Carriden Middle Limestone, are often represented by igneous rocks. In the journal of the bore at Springfield the topmost rocks for 11 fms. are called fakes and fireclay, and perhaps they represent the volcanic ash of Carriden Glen. Below these comes an impure limestone, 2 ft. 4 in. thick, which perhaps represents the Carriden Middle Limestone, and at depths of 48 and 62 ft. farther down other impure limestones occur, the top one, 25 in. thick, and the bottom one, 5 ft. 8 in. The journal only extends 36 ft. below the bottom limestone, but it is reported that the bore went to a depth of 60 or 70 fms. and cut a five-foot seam of good limestone, as well as a thick sandstone overlying a little coal. It seems not unlikely that the five-foot limestone reported may represent the thick Charlestown Limestone, which has been so much quarried at Charlestown on the north side of the Forth, and also the Hillhouse Limestone south-east of Linlithgow.

Another bore, No. 1 Burghmuir, reached, at a depth of 305 ft. beneath the rock surface, a four-foot limestone, below which came dark blaes 3 ft. 8 in. thick, and then nine inches of lime-fakes. It is probable that this bore started in beds below the lowest limestone of the Springfield bore, and that the limestone pierced by the Burghmuir Bore corresponds to the bed of limestone on the shore near Charlestown railway station—the bed taken as the base of the Carboniferous Limestone series in that locality—though the interval between it and the next important higher limestone is greater than that between the two limestones referred to at Charlestown. Before reaching the limestone the bore pierced a sandstone, 78 ft. thick, and an underlying thick shale with clay band ironstones: this thick sandstone may represent the sandstone in the cliffs at Charlestown above the limestone near the station. A little above this thick

sandstone, the bore records a bed of lime and iron, 11½ in. thick, which perhaps represents one of the thin limestones seen at Charlestown between the thick sandstone and the Charlestown Limestone. We have, therefore, in this locality drawn the base of the Carboniferous Limestone series at the base of the supposed outcrop of the Burghmuir Limestone. C. T. C.

CHARLESTOWN AND LIMEKILNS (FIFE).

The acceptance of the Cobbinshaw Limestone as the basal limestone of the Carboniferous Limestone series necessitated an alteration in the lower limit of the series in the neighbourhood of Charlestown, where the thick Charlestown Limestone has hitherto been regarded as the base.

The Charlestown Limestone is distinguished from the other limestones of the neighbourhood by its greater thickness (20 to 40 ft.), the presence of cherts, and the abundance of *Productus giganteus*. In precisely the same points it resembles the Petershill and Silvermine Limestone of the Bathgate Hills, and there can be little doubt that they belong to the same horizon. In the large quarries the Charlestown Limestone is succeeded by a thick mass of blaes, which pass up through fakes into a thick sandstone, a succession which is similar to that seen in the Silvermine Quarry, about two miles N.N.E. of Bathgate (Sheet 31). Beneath the limestone in descending sequence is a bed of shale, a foot or two thick, encrinital limestone two feet thick, another bed of shale, and then a thin bright coal, which sometimes passes laterally into coaly blaes.

The limestone, which probably lies on the horizon of the Hurlet Limestone of Cobbinshaw, is exposed on the shore below Charlestown railway station in a small faulted down patch with quaquaversal dip. It is a dark encrinital limestone, which lies about 150 ft. beneath the Charlestown Limestone. By excavation into the beach the following section was proved:—

	Ft.	In.
Blaes		
Dark encrinital limestone	4	0
Dark blaes with fossils	4	6
Coal, with pyritous band	0	10
Fireclay .. .. more than	3	0

This limestone is seen again on the shore opposite the school at Limekilns, whence its outcrop runs obliquely up the face of the cliff behind the village and is then lost beneath the covering of drift. It is exposed, however, on the east side of the Rosyth anticline at the mouth of the old fireclay mine at Sunnybank, north of Inverkeithing, and again at high-water mark a quarter of a mile west of Rosyth Farm. At the latter place the limestone seems to lie in a shallow basin, and is certainly faulted down against the Calciferous Sandstone series both to the south and to the west. From the black shales beneath the limestone Mr. Tait collected a suite of fossils very similar to those found in the shale beneath the limestone at Charlestown railway station.

This dark encrinital limestone is the lowest thoroughly marine limestone in the district, and as it resembles in character and

position the Hurlet Limestone of Cobbinshaw, it is taken as the base of the Carboniferous Limestone series in this district.

The limestones, which occur at horizons above the Charlestown Limestone, may be briefly described. The first of these is exposed in a little syncline in a railway cutting three-quarters of a mile west of Charlestown station, and lies about 180 ft. above the Charlestown Limestone. The following section is shown in the cutting:—

	Ft.	In.
Coarse volcanic tuff	2	0
Dark limestone	2 ft. to	2 6
Sandstone	2	0
Shale	2	0
Coal	1	0
Fireclay and blaes	6	0

Excepting a small isolated crop of limestone near the tuffs in the middle of Ironmill Bay, the next limestones met with are the three bands at Kinniny Point, the lowest of which is about two feet thick, with shale and a thin seam of coal beneath it. It is easily distinguished by its layers of *Lithostrotion irregulare*. Above it comes blaes containing ironstone nodules, which were wrought formerly along the outcrop, and then a calcareous sandstone, which contains occasional patches of tuff and exhibits a curious curved bedding. The Middle Kinniny Limestone, from 6 to 8 ft. thick and about 25 ft. above the lower band, is charged with encrinites, and crops out in the bed of the stream north of Balbougie ($1\frac{1}{2}$ mile N.N.E. of Inverkeithing). The Upper Kinniny Limestone is very hard, varies from one to two feet in thickness, and lies immediately on a bed of gannister about 80 ft. above the middle band. Inland it has been recognised in the burn below Balbougie. It is characterised by numbers of *Bellerophon*, and is probably the same as the top Hosie Limestone described by Dr. Crampton in the Campsie district.* H. B. M.

Bo'ness and Bathgate Coal Group.

Throughout the greater part of the area between Bo'ness and the southern margin of the one-inch map 31 near Leven Seat, a portion of the Bo'ness and Bathgate Coal group is represented by volcanic rocks, and these increase so much in thickness towards Linlithgow that for a time in this neighbourhood no coal seams appear to have been formed. Thus the outcrop of the coal-bearing strata may be divided into two areas—a northern area, extending from Bo'ness to near Linlithgow, and a southern area, extending from the southern edge of the map to the neighbourhood of Kipps; but neither the southern edge of the northern area nor the northern edge of the southern area are well defined. The intermediate area, which extends from Linlithgow southward to the neighbourhood of Kipps, is only about two miles in length along the strike, but it is a remarkable fact that up to the present time it has been found impossible to correlate any of the seams in the northern area with those in the southern.

* "Summary of Progress," *Mem. Geol. Sur.* for 1904, p. 100.

The development of the group to be described has been dealt with in various valuable papers by Mr. Cadell, to whom special thanks are due for much kind assistance rendered during the course of the revision. C. T. C.

WOODMUIR AND FOULSHIELS AREA SOUTH OF BREICH WATER (Sheet 31).

The coal crops shown in one-inch map 31 on the south side of the Leven Seat fault form the northern prolongation of the Wilsontown field, of which the following is the general section:—

	Ft.	In.
Wilsontown Main Coal	4	6
Strata	90	0
Maggie Bands * or Hogg Fence Ironstone	1	4
Strata	66	0
Wilsontown Gas Coal .. .. .. 9 in. to	1	8
Strata	84	4

These all dip to west and are repeated to the east by the anticlinal fold on the south side of Hendreys Course. On the eastern side the coals and ironstones have been proved by bores to occupy a shallow synclinal fold, and the Wilsontown Gas Coal is estimated to lie about 400 ft. above the Cobbinshaw Hurlet Limestone.

The Leven Seat fault with a downthrow to the north causes this fold to occupy a broader area on its northern side eastward of Hendreys Course, but the fold dies out to north, and the crop of the Main Coal forms the segment of a circle extending from west to east. In the hollow between the western side of this segment and Hendreys Course the Main Coal is reported to have been opened out, and from numerous bores it appears that it occupies another smaller shallow basin. Three hundred yards to the south of the Cairn, a shallow pit proved the gas coal to be very coarse. Between this smaller basin and the Woodmuir Coal-field a flat anticlinal arch must intervene.

The structure of the Woodmuir portion of the coal-field is very simple. From the Leven Seat fault to Longford Farm the general dip is W.N.W., but on the south side of the Caledonian Railway it changes to west, while the coal crops strike N. and S. and are brought nearer together in consequence of the increased dip, of 15° or 20°. The field is intersected by several cross faults, the more important of which will be shortly mentioned. On the south-east side of the Lanark road the outcrop of the Main Coal has been proved by crop pits, from the western side of Hendreys Course to the Bank Head dislocation, which strikes nearly east and west, crossing Skolie Burn about 630 yds. south of Blinkbonny and passing westwards close to Bank Head. The southern portion of the Woodmuir field was wrought some years ago by means of a shaft 40 fms. deep, and the workings proved several N.W. and S.E. faults. The colliery is now dismantled. On the south side of the Bank Head fault, in the Skolie Burn, an "ingoing eye" marks the position of the Wilsontown Main Coal, and a little distance to the east a pit reached the Wilsontown Gas Coal at 8 fms.

* The term "Maggie" is applied to ironstones of inferior quality.

The Bank Head fault has a downthrow of 27 fms. to north, and shifts the outcrops of the Wilsontown Main and Gas Coals on the north side some distance towards the east. Farther north the point where the crop of the Main Coal crosses the Skolie Burn is again fixed by an "ingoing eye," and the overlying strata are well exposed in the stream. This portion of the field was wrought as far as the Woodmuir east and west fault, by several shafts, the deepest reaching 52 fms. Coking ovens were built, and the Woodmuir Smithy Coal produced a fair coke, but all the works are now dismantled.

On the south side of the Woodmuir fault the average dip of the coal seams is 8° to 10° to W.N.W., but on the north side the structure is somewhat different. This fault has a downthrow of at least 36 fms. to north, and shifts the outcrop of the Main Coal nearly to Whole Stock, where the seam plunges down at an angle of 15° to a vertical depth of about 200 ft., and then changes to 3° and continues so for over half a mile in the direction of the present Woodmuir Pit. This field is at present wrought by the United Collieries Co., by shafts sunk a little to the south-west of Longford peat moss. A bore not far from the colliery gives the following section:—

	Ft.	In.
Limestone, Index	4	1
Strata	2	7
Coal No. 1	0	10
Strata	24	0
Coal No. 2	0	4
Strata	2	3
Coal No. 3	1	3
Strata	18	10
Coal No. 4, "China"	2	5
Strata	48	2
Coal No. 5	0	5
Strata	4	5
Coal No. 6	1	3
Strata	6	1
Coal No. 7	1	3
Strata	5	6
Coal No. 8	2	4
Strata	13	1
Coal, "Woodmuir Smithy"	1	11
Strata	12	1
Coal No. 10	0	7
Strata	12	5
Coal, "Lady Morton"	2 ft. to	2 10
Strata	20	8
Coal No. 12	1	7
Strata	23	1
Coal No. 13	1	5
Strata	5	3
Coal No. 14, "Craw"	1	9
Strata	4	3
Coal, Wilsontown Main	2	6

The China, Smithy, and Lady Morton are the seams wrought at the Woodmuir Pit, the last at 51 fms. from the surface. The shaft has been carried down to the Wilsontown Main. From the above section it will be seen that there is a large number of thin coals between the workable seams. One of these, No. 10, in the coalfield not far to the north, attains a thickness of 2 ft. 3 in.

and is known as the Splint. As a general rule all the workable coals increase in thickness towards the north, as the following table shows:—

	Woodmuir Colliery.	Loganlea Colliery.	Foulshiels Colliery.
	Fms. Ft. In.	Fms. Ft. In.	Fms. Ft. In.
China Coal.. ..	2 ft. to 0 2 6	0 3 3	0 2 9
Strata..	9½ fms. to 14 0 0	14 0 0	12 0 0
Woodmuir Smithy Coal	1 ft. 11 in. to 0 2 2	0 3 7	0 2 6
Strata	4 0 0	5 0 0	6 3 0
Lady Morton or Jewel Coal ..	2 ft. to 0 2 10	0 3 0	0 3 10
Strata	10 fms. to 14 0 0	11 3 0	9 fms. to 12 0 0
Wilsontown or Main Coal	0 4 0	0 5 0	1 0 7

In Woodmuir Colliery the Wilsontown Main Coal frequently splits up into two leaves with a parting of shale which varies from 4 to 10 ft. No. 3 Coal in this field is probably the representative of the Balbardie Parrot Seam.

At Loganlea and Foulshiels Collieries all the four seams are wrought, and the following comparative table shows the variations in thickness:—

	Loganlea.	Ft.	In.	Foulshiels.	Ft.	In.
China Coal	Roof, sandstone.			Roof, flakes.		
	Coal	2	0	Coal	2	6
	Dirt 2 ft. 9 in. to	0	6			
	Coal	0	9			
		3	3		2	6
Woodmuir Smithy Coal	Roof, sandstone.			Roof, sandstone.		
	Blaes	1	2	Blaes	0	4
	Coal	0	6	Coal	0	4
	Ribs	0	2	Stone	0	1½
	Coal	1	9	Coal	2	0
		3	7		2	9½
Lady Morton or Jewel Coal	Pavement, fireclay.			Pavement, fireclay.		
	Coal, "Craw" ..	0	10	Coal, "Craw" ..	0	4½
	Roof, fireclay ..	9	0	Roof, blaes	4	6
	Coal	3	0	Coal	0	9
				Dirt	0	8
		12	10	Coal .. 3 ft. 10 in.	0	4
				„ Parrot	1	0
				„	1	1
					8	8½
Wilsontown Main Coal	Coal, "Craw" 6 in. to	0	2	Coal, "Craw" ..	2	0
	Roof, sandstone ..	2	6	Roof, fireclay ..	7	0
	Coal	0	10	Coal	1	1
	Dirt	0	10	Fireclay	1	6
	Coal	2	0	Coal .. 6 ft. 7 in.	2	6
	Dirt	0	7	Wild stone	0	6
	Coal	0	9	Coal	1	0
		7	8		15	7

In the Lady Morton Seam at Foulshiels there is, near the base, a band of wild parrot which varies greatly in thickness and quality. The Wilsontown Gas Coal, which lies 25 fms. below the Main Coal, is too thin to be workable: its position has been proved in bores to the east of Longford and also at Foulshiels, where its average thickness is 9 in. This seam has been correlated with the Lesmahagow Gas Coal of Lanarkshire. At Foulshiels, the Balbardie Coal is not workable, but is known to be 18 to 24 ft. above the China Coal. The quality of coal raised from these three collieries varies from second to third class. Between each of the seams the thickness of the separating strata also varies considerably. Between Longford and the outcrop of the Wilsontown Gas Coal to the east of Woodmuir a large number of bores have been put down, and these show a total thickness of 525 ft. of strata between the Index Limestone and the highest bed of the Lower Limestone group. J. S. G. W.

BATHGATE AREA (Sheet 31).

Excepting the presence of the Bathgate lavas, the Bo'ness and Bathgate Coal group shows, in this area, a development very similar to that in the country between Leven Seat and Foulshiels already described. Here, also, the valuable coal seams occur only in the upper portion of the group, which, fortunately, in the Bathgate area is comparatively free from volcanic rocks.

Exposures are few, and to the south of Bathgate the only surface indication of this division is the presence of a long line of coal-pits, which have of late years shown a tendency to advance ever farther towards the west, as the coals have been sought at continually increasing depths. But from Bathgate northwards the outcrop of the basalts underlying the workable coal seams can readily be followed, while to the west occasional exposures of the Index Limestone mark the limit in this direction of the surface extension of the group.

For accurate knowledge concerning any but the volcanic portion of the series, we are almost everywhere in this district forced to rely upon mining information, which has been generously supplied. The coal seams run almost due north and south with a dip of about 25° towards the west. They are traversed by two east and west dolerite dykes, and are displaced by a series of east and west faults, whose downthrows are more often towards the south than the north. The most important of the faults — that against which the Bathgate Hills terminate on the south—is reckoned to have a downthrow of about 60 fms. to the south.

Until recently, accurate knowledge regarding the sequence of the strata has been confined to the upper portion of this division, which contains the workable coal seams of the area. But in 1903 * a bore was put down at Moss-side Colliery, east of Durhamtoun, which has proved the whole succession from the worked coals down to the Lower Limestone group. The volcanic rocks were here found in greatly diminished proportion compared with their development a short distance farther to the north, at

* Since the publication of H. M. Cadell's paper on "The Carboniferous Limestone Coal-fields of West Lothian," *Trans. Inst. Min. Engrs.*, 1901, vol. xxii. p. 372.

Bathgate, so that it is now possible to be certain for the first time of the chief characteristics of the sedimentary sequence in this neighbourhood. The most noticeable feature is that the upper subdivision, which contains the four or five workable coal seams of the district, corresponds closely to the Possil group* of the Glasgow area, and is separated from the underlying comparatively barren measures by a Parrot Coal which is almost certainly the same as the Wilsontown and Lesmahagow Gas Coal of the south, and may also be taken as the representative of the Gas Coal of the west country. The Possil group in Linlithgowshire is, however, much poorer in blackband ironstones than in the typical area near Glasgow, and the underlying subdivision is in every way less productive than in the west.

We shall first give the Moss-side section of this lower subdivision.†

	Ft.	In.
Wilsontown Gas Coal.		
Whinstone (basalt)	5	11
Blaes, fakes, and fireclay	4	1
Whinstone (basalt)	44	1
Blue blaes	0	6
Coal with ribs	1	0
Sandstone	8	8
Blaes	4	0
Coal	1	2
Blaes, etc.	14	3
Coal	0	3
Fakes and sandstone	5	5
Coal (burned)	0	10
Sandstones with blaes	24	6
Sandstone	18	6
Blaes and balls	23	3
Coal	1	2
Blaes and sandstone ribs	10	8
Sandstone	18	0
Blaes	6	8
Brown rib	0	1
Fakes	0	1
Limestone band	0	5
Blaes and faky rib	1	2
Coal	0	7
Sandstone	11	0
Blaes and ribs	6	11
Coal	0	3
Faky blaes and balls	6	8
Coal	0	2
Sandstone	12	10
Blaes	9	6
Irony rib	0	5
Blaes	1	6
Sandstone	6	4
Blaes	13	1
Sandstone and fakes	12	7
Blaes and balls	13	11
Limy blaes with shells. Topmost Hosie Limestone.		
	290	5

* This correlation is based upon the work of R. G. Carruthers, whose results will be published in the memoir dealing with the Geology of the Glasgow district.

† Corrected for the dip at 25° so as to give the true thicknesses.

We may now pass on to consider the upper subdivision or Possil group, the development of which in the neighbourhood of Bathgate is illustrated by the following vertical section. The details down to the Main Coal * were obtained from a bore put down a mile to the west of the outcrop of the Index Limestone at Balbardie; while, between the Main and Gas Coals, the section is merely the upward continuation of that quoted above from the journal of the Moss-side Bore.†

	Ft.	In.
Index Limestone.		
Blaes	4	3
Coal	0	6
Whinstone (basalt)	35	0
Sandy fireclay	4	4
Balbardie Gas Coal—		
Wild Gas Coal	0	3
Cannel Coal	0	7
Ironstone	0	3
Fireclay	1	10
Free Coal	1	6
Fireclay	0	5
Sandstone, fakes, and blaes	11	1
China or Shaly Coal—		
Coal	1	1
Blaes band	0	11
Wild Cannel Coal	0	6
Coal	0	5
Sandstone, fakes, and blaes	16	0
Ironstone	0	1
Blaes	0	2
Cement bed	1	0
Coal	0	4
Sandstone, fakes, and blaes	11	5
Coal	0	1
Sandy fakes, hard	20	9
Sandstone, fakes, and blaes	13	10
Coal	0	6
Fakes and sandstone	13	8
Blaes	0	10
Two-Foot Coal (?)—		
Coal	0	2
Fireclay	0	1
Coal	0	2
Blaes	0	2
Coal	1	9
Fireclay	0	2
Sandstone, blaes, and fakes	8	11
Fiddle Coal (?)	1	4
Fireclay	0	7
Fakes and blaes	11	11
Coal	0	4
Blaes	0	2
Sandstone	2	0
Jewel Coal—		
Coal	0	3
Blaes rib	0	3
Coal	2	8
Carry forward	172	6

* These have been already given by H. M. Cadell, "The Carboniferous Limestone Coal-fields of West Lothian," *Trans. Inst. Min. Engrs.*, 1901, vol. xxii. p. 372.

† As before, correction has been made for a dip of 25°.

	Ft.	In.
Brought forward ..	172	6
Blaes, fakes, and sandstone	6	10
Coal	0	3
Fireclay	0	2
Fakes and blaes	4	6
Coal	0	6
Fireclay	0	9
Fakes	11	3
Craw Coal, foul	1	8
Rocky plies	7	5
Blaes	2	0
Main Coal—		
Coal	0	7
Fireclay	0	3
Coal	1	4
Blaes, coaly	0	3
Coal	0	8
Fireclay rib	0	2
Coal	1	6
Cement rib	0	2
Coal	1	0
Sandstones with shales	78	3
Blaes	8	9
Ironstone	0	3
Blaes	0	8
Ironstone	0	5
Blaes	4	11
Ironstone	0	3
Blaes	9	2
White Rib	0	1
Irony Band	0	6
Blaes	0	3
Maggie Bands		
Grey sandstone	1	10
Coal (with two ribs)	1	0
Sandstone	16	4
Blaes (with iron ribs towards base)	7	3
Coal	0	5
Faky fireclay	0	11
Sandstone	14	9
Blaes	1	10
Limy sandstone and balls	3	3
Faky blaes	1	7
Sandstone	1	1
Coal with ribs	1	7
Blaes	0	11
Coarse sandstone	2	3
Blaes and balls	3	10
Sandstone	14	5
Fakes and blaes	6	7
Coal (Blind Coal †)	0	6
Grey sandstone and fakes	3	7
Whinstone (basalt)	49	10
Wilsontown Gas Coal—		
Parrot Coal mixed with Whinstone..	4	0
	455	0

Combining these figures with those already given for the lower subdivision, we find that the Bo'ness and Bathgate Coal group in the Bathgate district has a total thickness of about 750 ft.

† "Blind Coal," coal that burns without smoke or flame, having lost most of its volatile constituents. A variety of anthracite.

The whinstone beds in the foregoing sections consist of vesicular olivine basalts, and most of them are no doubt lava flows. Some of them, however, seem to behave as intrusions, and the Gas Coal, where it was encountered in the Moss-side Bore, was found to be pierced by ramifying basaltic veins, although, strange to say, the quality of the coal does not appear to have been materially impaired.

We now proceed to summarise in comparative tables Mr. Cadell's main conclusions relating to the variations in the development of the group which have been proved in the collieries at present working in the district.*

	Mosshall near Foulshiels.		Boghead near Durhamtoun.		Balbardie near Bathgate.	
	Ft.	In.	Ft.	In.	Ft.	In.
INDEX LIMESTONE.						
Strata	24	0	35	0	44	0
BALBARDIE SEAM	2	0	6	10	4	5
Strata	7	0	16	0	11	0
CHINA OR SHALY COAL	2	10	2	4	2	11
Strata	86	0				
WOODMUIR COAL	2	6	98	0	105	0
Strata	54	0				
JEWEL OR LADY MORTON COAL ..	5	5	3	7	3	2
Strata	37	0			24	0
CRAW COAL	1	7	53	0	1	8
Strata	19	0			9	0
MAIN COAL	6	1	7	2	5	11
	247	5	221	11	211	1

In none of the localities mentioned in these tables is there any thick sandstone, but Mr. Cadell† gives the record of another bore, put down near Hilderston Farm, farther towards the north, in which a thick sandstone comes in and doubles the ordinary interval separating the Index Limestone and the Balbardie Seam. The portion of the journal which bears upon this point is as follows :—

	Ft.	In.
Index Limestone	4	11
Blaes and balls	4	7
Light fireclay and ironstone balls	9	9
Fakes	2	0
Sandstone	41	2
Fakes	18	0
Balbardie Seam—		
COAL	1	4
PARROT COAL	0	3

The coal seams mentioned in the tables are generally much split up with dirt and stone bands, as was shown in the previous

* The figures in the first column are corrected for a dip of 25°.

† *Op cit.* p. 372.

detailed section. No parrot or cannel occurs with them in the Foulshiels and Blackburn district, but farther north, at Bathgate, it is found both with the Jewel, the China, and the Balbardie seams; but more particularly with the first and last named, which are in consequence often termed the Big and Little Parrots respectively. At the levels chiefly worked at present the Balbardie Seam is especially valuable, and is accompanied by a blackband ironstone which is wrought with the coal; but trials made at greater depths point to a deterioration in the quality of the seam towards the west. In the old days of crop workings, moreover, this coal does not appear to have been so much sought after as at present, for it was the Jewel, and not the Balbardie, which was then known as the "Parrot Seam." The following section of the latter is quoted by Mr. Cadell from a report drawn up by David Landale in 1853, relating to the old Hilderston Colliery, situated about a mile and a half north of Bathgate.

	Ft.	In.	
Roof, coal and stone in alternate layers ..	1	6	
Coal	0	10	5 ft. 1½ in.
Stone	0	1½	
Coal	0	1½	
Stone	0	7	
Coal	0	5	
Stone	0	1	
Coal, free	1	4	
Stone	0	1½	
Coal	0	6	
Coal, Parrot	1	0	
Pavement, sandstone.			

At Kipps,* the most northerly of the collieries, which, in times gone by, have worked the Bathgate coals, the same seam was 2 ft. 9 in. thick, with 3 in. of parrot below, while in the present deep workings of Balbardie the parrot has disappeared altogether. The inconstancy of individual bands of parrot, compared with the coal seams with which they are associated, is a noteworthy feature of this part of the field.

Where there is no specially valuable parrot or ironstone, it is the Main Seam, as its name implies, which is regarded as the most important coal in the field, but the other seams and the Jewel in particular are also extensively wrought.

There are indications, it is to be feared, that the Bathgate volcanic rocks increase in thickness to the west under the outcrop of the Lower Coal Measures. Of course this development can only hold for a limited area, since the group is free from volcanic intercalations where it rises to the surface once more along the other side of the Lanarkshire basin, but it is a point which must not be lost sight of in forecasting the future development of the coal-field. To illustrate this increase we may, in the first place, compare the records which Mr. Cadell† quotes of the old workings near the crop at Hilderston and the journal of the bore put down half a mile to the west, close to the farmhouse.

* For many details the reader should refer to H. M. Cadell's paper.

† "The Carboniferous Limestone Coal-fields of West Lothian," *Trans. Inst. Min. Engrs.*, 1901, vol. xxii. pp. 391, 392.

HILDERSTON COLLIERY.

	Ft.	In.
RED COAL (Balbardie) ..	1	9
Strata	36	0
BLACK COAL (shaly)	1	8
Strata	42	0
TWO-FEET COAL	1	4
Strata .. ..4 ft. to	10	0
FIDDLE COAL..	4	10
Strata	24	0
PARROT SEAM (Jewel) ..	6	0
Strata	42	0
MAIN SEAM, with ribs ..	3	0

HILDERSTON FARM BORE.

	Ft.	In.
INDEX LIMESTONE	4	11
Strata	75	6
BALBARDIE SEAM	1	7
Strata	38	0
SHALY COAL—		
COAL, foul	1	3
Fakes and blaes ..	4	9
COAL, foul	1	10
Coaly fireclay and balls ..	0	5
Ash, conglomerate	30	5
Limy fakes	27	1
Limy fakes or ash	74	4
Fakes and coal ribs (? Main)	5	3
Faky sandstone	12	3
Grey fakes	1	9

The "Limy Fakes" of the bore journal no doubt are igneous rocks of some description, either ashes or decomposing basaltic lavas.

The same increase is shown, though in a very minor degree, in the deeper workings of the Balbardie Colliery; for the sediments, which, near the outcrop, intervene between the Index Limestone and the Balbardie Seam give place, farther west, to a vesicular olivine basalt which is probably a true lava flow.

There is, however, no occasion to take a desponding view of the matter, for it will be shown subsequently, when the Upper Limestone group comes to be discussed, that the somewhat discouraging results of a deep bore (Vivian's Bore), which started a little above the base of the Coal Measures south of the Bathgate fault, and failed to prove workable coals, are most probably due to faulting, and not to an increasing thickness of volcanic rocks to the west. E. B. B.

THE KNOCK TO COCKLERUE (Sheet 31).

The Bo'ness and Bathgate Coal group is replaced in this area by the volcanic rocks, with the exception of the narrow belt of coal-bearing sediments immediately below the Index Limestone. As already mentioned, these coals were formerly wrought at Hilderston and at Kipps. H. B. M.

COCKLERUE TO LINLITHGOW (Sheet 31).

It does not seem possible that many of the sedimentary beds of the Bo'ness and Bathgate Coal group were deposited in this area; but perhaps some of them occur here and there between the flows, and may in the future be revealed by borings. Up to the present time the results obtained by the few borings here made in the rocks in the position of the group referred to do not encourage further prospecting. One at Mains Maltings, a quarter of a mile N.E. of Kettleston, proved only "whin" of various colours to a depth of 70 fms., while another at Loch Mill traversed some 40 fms. of "whin" and a rock described as "fireclay," which latter is probably ash in reality, with sandy partings at intervals. The well at the Avon Print Mill, 400 yds. north of Linlithgow Bridge, after

passing a few feet of strata below the Index Limestone pierced 120 ft. of "whin." Igneous activity continued until the close of the period during which the productive measures were being laid down elsewhere. G. W. G.

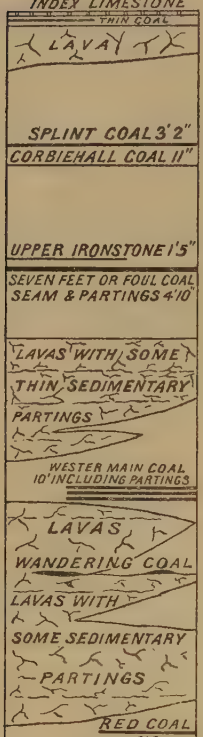

FIG. 10.—Generalised Section of the Bo'ness and Bathgate Coal Group near Bo'ness (scale 200 ft. to 1 in.).

LINLITHGOW TO BO'NESS (Sheet 31 in part).

In the northern part of the area this group includes two chief divisions of coal-bearing beds —an upper and a lower—separated by thick bands of igneous rock, in places more than 300 ft. thick, most of which appear to represent lava flows. The total thickness of the group, including all the igneous bands excepting one, which occurs in the lower portion and is certainly of intrusive character, is about 1050 ft. This estimate is made from the section in the Snab Pit (No. 1), Kinneil, and from a boring put down near No. 9 Pit, Grange. The thickness of coal, including all seams not less than a foot thick, amounts in these sections to 29½ ft., but it is to be noted that the Wester Main Coal, a seam which is in places thicker than any other but only occasionally found, is not represented in them. The accompanying generalised section shows the positions and names of the chief coals in the northern part of the area, where the coals are best developed.

The strata between the Carriden Upper Limestone—the top bed of the Lower Limestone group —and the Carsey Coal are about 65 ft. thick, and include a considerable proportion of shale and various coals too thin to be worked. The Carsey Seam is also thin, but is reported to have been formerly worked near Carriden Glen, and two day-levels have recently been driven for short distances along it from the outcrop 200 and 250 yds. slightly south of east of Carriden Church. At the mouth of the eastern level a bright coal at least a foot thick is exposed. In the boring near No. 9 Pit, Grange, the section of the seam is as follows:—

	Ft.	In.
Coal, strong	1	1
Shale	0	3
Coal, strong	0	7

Shales with ironstone balls overlie the coal, and "fakes" and sandstone come below. In a sinking in No. 1 Pit, Carriden, the Carsey Coal is reported to be 32 in. thick, but much mixed with dirt partings: in a boring near Muirhouses (south of Bridgeness) it was 18 in., and it is said to be of the same thickness also in part of the deep Kinneil workings, several miles west (the general direction of dip) of the outcrop.

In the boring near No. 9 Pit, Grange, the distance between the bottoms of the Carsey and Smithy Coals is about 24 ft., which is somewhat larger than usual. In some places, for instance, the bore near Muirhouses just referred to, an impure calcareous band, said by Mr. Cadell to be an unfossiliferous marl, occurs a little above the Carsey Coal.

The Smithy Coal is generally somewhat less than 3 ft. thick, but often of good quality, particularly in the southern part of the Kinneil workings, where it is at present being mined at a depth of 260 fms. below sea-level. It contains no anthracite as the name would imply, but is a gaseous coal and is classed as a good house and coking coal. In some parts of the Grange area it is too thin to be profitably mined, the difficulties of working being increased by the weakness of the roof which is formed of shale. But in other parts of this area it has been found by boring to be better developed, and new pits have lately been sunk to it both at Grange and Carriden.

The roof of the seam has long been known as a pyritous richly fossiliferous shale. It has this character in the Kinneil workings, where the remains of *Lingula mytiloides* are especially abundant for an inch or two immediately above the coal, but are somewhat distorted. The seam has been worked on a small scale at an abandoned mine about half a mile N.N.E. of Upper Bonnytoun, where it has the usual roof and varies in thickness from two to three feet.

The strata between the Smithy and the Easter Main Coals are generally about 80 ft. thick, irrespective of an intrusive sill or laccolite which often occurs with them, but in the mine near Upper Bonnytoun the total interval, including a band of igneous rock, about 30 ft. thick, which is probably a lava flow, is about 66 ft. Mr. Cadell * states that a marine band, containing fish scales and *Lingula squamiformis*, occurs in a shale 2 fms. below the East Main Coal in No. 6 Pit, Grange, and that it has also lately been met with in the new sinkings (No. 1 and No. 2 Pits).

From the loose blocks carried to the shore from these sinkings, Mr. Tait has collected the remains of various fossil fishes, which have been named by Dr. Traquair as follows:—

Pleuroplax sp., tooth.
Oracanthus armigerus Traq., teeth.
Tristychius minor Ptl., spine.
Megalichthys sp., scales.
Rhizodopsis sp., scales.
Strepsodus striatulus Traq., teeth.
Cœlacanthus abdenensis Traq., plates.
Elonichthys sp., scales.
Eurynotus crenatus Ag., scales.

Dr. Traquair states that "the above list is interesting as containing *Oracanthus armigerus* and *Cœlacanthus abdenensis*, characteristic of some Lower Carboniferous fish beds, which, like the present one, also contain abundant remains of *Lingula squamiformis*. Such beds are the so-called bone bed at Abden in Fifeshire, and the shale in

* "The Fossiliferous Rocks of the Borrowstounness Coal Field," *Trans. Geol. Soc. Edin.*, vol. iv. p. 321.

connection with a seam of blackband ironstone of the "North" coal worked at Niddrie in Midlothian." (MS. note by Dr. Traquair.)

In the eastern part of the coal-field, the East Main Coal—a clean house coal of very good quality—is from 3½ to 4½ ft. thick, and it is being extensively worked under the Forth both at the Grange (Bridgeness) and Carriden Collieries. Its somewhat splinty character enables it to be mined in large blocks; the roof is usually sandstone. In the western part of the district, however, in the Kinneil Collieries, the quality is much inferior, and the seam is not worked.

Immediately above a thin coal, which lies 2 or 3 ft. above the East Main in the Carriden Colliery, a band of shale, 2 or 3 in. thick, is crowded with *Lingula squamiformis*. This fossiliferous horizon was sought in vain in the Bridgeness workings and in the Furnace-yard Pit of Kinneil, though the thin coal is present in both places.

The interval between the East Main and the Six-foot Seam amounts to about 40 ft. at Bridgeness and Carriden, and in the Snab Pit, Kinneil, to more than 53 ft. In the eastern part of the coal-field the Six-foot Seam is sometimes called the Foul Coal, being split up by partings of shale and fireclay to such an extent that it is not worked. Farther west, however, at Kinneil, it is mined—most of it as a steam coal—and the bottom part is an excellent Parrot, about eight inches thick, which is sent up separately from the rest. The usual section in the workings is—

	Ft.	In.
Faky sandstone		
Shale	2	4
Coal	0	6
Fireclay	0	8
Free Coal	1	6
Fireclay	0	4
Free Coal	1	7
Sclit (blaes)	0	4
Coal, with a seam of Parrot varying in thickness from 0 to 10 in.	1	2
Faky fireclay		

In the Carriden Pit a coarse sandstone usually lies two or three feet above the coal, but sometimes comes down on or into the seam, in which case it is mixed irregularly with stripes of coal, as if the materials of the two beds had been jumbled together under water before consolidation. The interval between the Six-foot Seam and the seam of the Lower Parrot and Ironstone is but small. In the Red Coal Pit (a mile south of Bridgeness) it is only 6 ft. 3 in., which is less than usual. The different bands of ironstone, and those parts of the valuable gas coal that are thick enough to work, appear to have been all removed, but it is advisable to record the sections proved in some of the old workings. Mr. Cadell * gives the following section from the Red Coal Pit:—

	Ft.	In.
Brown Ironstone	1	0
Fireclay with ironstone nodules..	0	2
Coal, Parrot and Cannel	0	9
Blackband Ironstone	0	3
Coarse fireclay and ironstone nodules	0	10

* *Trans. Inst. Min. Eng.*, 1901–2, vol. xxii. p. 379.

He also states that the section in the Bridgeness workings in 1901 was as follows:—

	Ft.	In.
Hard shale and kennel		
Common or Craw Coal	1	0
Shale	1 ft. to 3	0
Coal, Parrot	1 ft. to 1	2
Shale and ironstone nodules		

The seam was also formerly worked from the Schoolyard Pit, Bo'ness, underneath the sea opposite Bo'ness harbour and dock, where it gave the following section:—

	Ft.	In.
Common Coal	3 in. to 0	10
Parrot Coal	1 ft. 3 in. to 1	7
Blackband Ironstone	3 in. to 0	10

In No. 9 Pit (Kinneil), about 250 yds. north of Bonhard House, the section showed the following beds:—

	Ft.	In.
Shale	10	0
Coarse Ironstone	1	6
Shale	3	0
Foul Parrot Coal	6	8
Brownstone Ironstone	10 in. to 0	3
Sandy fireclay	2 in. to 0	3
Parrot Coal	8 in. to 1	6
Blackstone Ironstone (inferior in quality)	8 in. to 0	10
Dross Coal	0	6
Coarse fireclay	9 in. to 1	0
Dross Coal	2 ft. 2 in to 2	6
Black hard shaly sandstone	0	9
Dross or Foul Coal	1	6
Sandstone		

It is stated that, in the abandoned pit near Upper Bonnytoun, this seam is hardly represented, though the ironstone was of good quality farther north-east between Bonsyde and Bonhard Mill. In the Kinneil Collieries the position is marked by an impure ironstone, 2 in. thick, and some thin bands of rough coal which are too much mixed with layers of stone to be workable. The shale above the brownstone portion of the seam is said to have been richly fossiliferous in No. 9 Pit, Kinneil, and the blocks of parroty shale in the waste heap at the old pit mouth contain abundant specimens of *Naiadites obesa*. The same fossiliferous horizon was also found in the Red Coal Pit, but it does not appear to be represented in the Kinneil and Carriden workings. Mr. Cadell states that in No. 5 Pit, Grange, a band containing a similar assemblage of fossils occurs a few feet lower in stratigraphical position.

The beds between the Lower Parrot and Ironstone Seam and the Red Coal are about 97 ft. thick in Pit No. 6, Grange, and the upper portion includes a thin coal called the Fireclay Seam, 14 in. in thickness, and is underlain by a fireclay, 5 ft. 4 in. thick, which was formerly worked.

The Red Coal is now being mined under the Forth from No. 6 Pit, Grange, where it is 3 ft. thick and is classed as a gas or house coal of second-class quality; above the seam comes a faky blaes (sandy shale), 9 in. thick, and then a hard sandstone which makes durable roofs

for the underground roads. This sandstone is rather more than 40 ft. thick, and is quarried along the outcrop half a mile south of Grangepans, where it is surmounted by a band of igneous rock that probably represents a lava flow. As Mr. Cadell has pointed out * this sandstone is not represented near Upper Bonnytoun, the Red Coal being there separated from the overlying lava only by a little shale—sometimes less than 6 in. thick. The coal is exposed at the mouth of an old day-level in this locality, where it is only 18 in. thick and mixed with bands of dirt, but it is reported to be thicker and better within the mine. In the Snab Pit shaft No. 1, a seam, composed of 6 in. of coal at the top and 14 in. at the bottom, separated by 16 in. of white calm (clay), lies immediately below a thick bed of igneous rock. This seam may possibly be in the position of the Red Coal, but Mr. Cadell regards it as a representative of a higher seam—the Wandering Coal, to be shortly described—because a band of igneous rock, 4 ft. 6 in. thick, comes almost immediately below it (see Fig. 10).

Most of the sedimentary partings separating the different bands of igneous rock that come between the upper and lower coal-bearing beds of this group cannot be traced satisfactorily, being either thin or deeply covered by drift. In the Kinglass Pit (also called the Mingle Pit, about 370 yds. slightly west of south of North Kinglass) the two lowest whinstones are separated by a thin hard sandstone, called "red-stone," and above them come 30 ft. of shale followed by another bed of whin, about 20 ft. The "Wandering Coal" seems to have been found almost by itself, apart from any other sediment, in a great mass of whin and to have been formed of a local accumulation of vegetable matter, washed down into an irregular hollow on the surface of the underlying lava, which was shortly covered again by another flow. It was first met in No. 3 Pit, Kinneil (about 230 yds. south-east of the Newtoun cross roads), where it was 9½ ft. thick, and of excellent quality, but disappeared rapidly, in distances varying from 50 to 100 yds., in all directions from the shaft bottom. In No. 18 Pit, Kinneil (Lothians Pit), its distance above the Red Coal is 158 ft. This seam was also found in No. 13 Pit, Kinneil (420 yds. W.S.W. of No. 3).

Above the igneous material forming the roof of the Wandering Coal comes another band of sediments, including the Wester Main Coal, which also seems to have been entirely or almost entirely worked out, though it was thicker and much more widespread than the Wandering Coal. The thickness of this band averages perhaps 30 ft., but it is much thicker in some places, for instance in the Burn Pit (near North Bank), and in the Mingle Pit (nearly half a mile north-west of North Bank), which went down 144 ft. before it reached the coal and pierced no whinstone above it. The following section is taken from No. 18 Pit, Kinneil (Lothians Pit):—

	Ft.	In.
Freestone roof	40	0
Shale	0	9
Coal	1	4
Fireclay	1	0

* "Volcanic Rocks of the Borrowstounness Coal-Field," *Trans. Edin. Geol. Soc.* 1880, vol. iii. p. 322.

	Ft.	In.
Coal	1	4
Calmstone	1	0
Coal	1	6
Blaes	1	1
Coal	3	3
Fireclay	1	0
Greenstone (whin)	60	6

The total thickness of the seam, including three partings, is here more than ten feet, which was, however, much exceeded in other places.

The outcrop of the seam is said to pass about 150 yds. east of Bo'ness Railway Station and thence into the sea at the old harbour close to the docks. Near, and for some distance east of, North Kinglass, a group of large "sits" indicates the position of the old shallow workings. The seam was mined also in some old crop pits a few hundred yards south-west of North Bank. On the south side of the large east and west fault with a downthrow to the north that passes a third of a mile S.S.W. of North Bank, the seam must run along the narrow slack extending in a S.S.W. direction to a locality 150 yds. slightly west of north of the monument on Bonnytoun Hill. A coal seam and old crop workings have lately been disclosed in this locality, and a boring proved the following section:—

	Ft.	In.
Surface	5	3
Coal	2	6
Fireclay	0	9
Coal	2	5
Dark fireclay	7	10
Hard Burnt Coal	1	9
Fireclay	2	0
Soft whin	21	0

A seam, said to be 7 ft. thick,* and with a roof and pavement of whinstone, was formerly worked in a shallow pit about 350 yds. E.N.E. of Swordie Mains, and is in all probability the same coal. In bore No. 8 Muirhouse, the seam was found at a depth of 150 ft. below the top of the whin and showed the following section:—

	Ft.	In.
Fireclay and Coal	3	7
Foul Coal	0	8
Fireclay and Coal	0	10
Foul Coal	2	5

In the Snab Pit (No. 1) the whinstone, which comes above the supposed position of the Wester Main Seam, is no less than 265 ft. thick. It is succeeded by a parting, 5 ft. 6 in. thick, of shale, coal and "marledstone," overlaid by another bed of whin, 20 ft. thick, and the upper coal-bearing sediments.

No seam in these upper beds is at present worked. In the Snab Pit (No. 1) the Seven-foot Coal—which lies about 74 ft. above the bed of whin last mentioned—is called the Foul Coal or the Four-foot Coal, and its usual thickness is about 4 ft. 10 in., including a 4-in. parting of shale near the middle (see Fig. 10).

* This estimate probably includes various partings.

The Upper Ironstone Seam is only 4 ft. 10 in. above this coal, and its average section is—

	Ft.	In.
Coal	1	2
Stone-rib	0	9
Blackband Ironstone	1	5

It was formerly extensively worked from the Snab Pit, as far as 1000 yds. south-west of the Newtoun cross roads, for the sake of the ironstone, which was smelted at the Kinneil Furnaces.

The Index Limestone does not seem to have been recognised in the shaft of the Snab Pit No. 1. In the recorded section of this shaft a limestone, 15 in. in thickness, is indicated just below a band of whinstone, 51 ft., and above this whinstone comes a foul coal, 13 in. thick, overlaid by another bed, 5½ ft., which is termed "bastard green whin." It seems possible that the so-called limestone may be a veined portion of whin, and that the "bastard green whin"—which is 122 ft. above the Splint Coal—may be the Index Limestone. In the cliff behind Bo'ness Distillery the interval between the Index Limestone and an underlying bed of igneous rock, about 24 ft. thick, is nearly 10 ft. A coal, from 2 to 4 in. thick, occurs 2 or 3 ft. beneath the limestone, and below this coal there is a fireclay, which was formerly used for brickmaking. The igneous material rests on a coarse sandstone about 11 ft. in thickness.

The upper coals are found only in the western part of the area, the dip being generally in a westerly direction, though with many local variations, and at angles varying from 7° to 22°. In the Grange (Bridgeness) workings about 400 yds. south-west of Bridgeness Pier a gentle anticline strikes nearly north and south, and continues some distance inland where it affects the outcrop of the lava that overlies the Red Coal. West of this anticline comes a shallow syncline followed by another parallel anticline, the axis of which passes about 400 yds. east of Bo'ness Docks. Still farther west the dip is generally westward, but in the north-east portion of the Kinneil workings the beds are sometimes flat or inclined north-east. In the area near Bonside and Bonhard Mill, where the beds are for the most part drift covered, the Lower Parrot and Ironstone Seam has been worked at levels considerably lower than the surface position of this seam farther west, and it seems probable that this is due to a local change of dip towards the east.

The largest fault known landward is the east and west dislocation passing about 700 yds. south-west of North Bank, where the downthrow is to the north about 20 fms. Its course westward is uncertain, but in the workings in the Upper Ironstone, 400 yds. west of Borrowstoun Mains, a fault was proved, striking nearly east and west and with a considerable downthrow to the north, which may represent a continuation of it.

The occurrence under the foreshore and the Forth of certain coals of the lower division considerably east and north of their outcrops inland, is mainly due to the presence of two other faults which also strike nearly east and west and have a downthrow to the north. At Bridgeness the throw of the southern fault amounts to about 32 fms., while that of the northern one is about 12 fms., but the beds on the north side dip to the north for a distance of 700 yds., so that, about

480 yds. off Bridgeness Pier, the East Main Coal is 569 ft. below sea-level. The workings have proceeded about 450 yds. farther seaward across a shallow basin, at the other side of which the strata dip in a southerly direction. In the Carriden Pit the inclination of the northern fault to the north is well seen, and is unusually low—being only 45°.

In the Kinneil workings neither of these faults can be recognised with confidence. It seems probable that they both decrease westwards, and perhaps unite about a third of a mile west of Bo'ness Railway Station.

All the Bo'ness Coal seams appear to diminish in thickness on the south side of a line drawn east and west about a mile and a half south of the Forth, while the volcanic rocks increase. Pits have been worked for short periods in various places on the south side of this line, for instance, near Upper Bonnytoun, at Muirhouses (about a mile north of the west end of Linlithgow Loch), and near Balderston —rather more than half a mile W.S.W. of Swordie Mains—but none of these has been successful.

In the Muirhouse Pits No. 1 and 2, two coals, separated by 6 fms. of coarse freestone, were mined, but neither is much more than 2 ft. thick. The lower seam is about 35 ft. above the top of the thick whinstone that underlies the upper coal-bearing beds. About 120 yds. south of Swordie Mains a coarse yellow freestone, lately exposed, probably represents the horizon just alluded to, and is of considerable interest, as Mr. Cadell has found it to contain small grains of garnet in great abundance. Subsequently Mr. Grabham found in it tourmaline, rutile, zircon, magnetite and leucoxene. In No. 3 Pit, which is some distance west of the others and no doubt in higher beds, a band of good cannel coal, 5 or 6 in. thick, was met with, which lay under, and seemed in places to be partly replaced by, an ironstone of good quality.

No satisfactory information has been obtained about the Balderston Pit, but it must have started in beds considerably below the Index Limestone. It is said to have been 12 fms. deep and to have reached a coal, 3 ft. 8 in. thick, which was mixed with dirt partings. A number of shallow bores have been put down in this locality, but it is doubtful whether their positions have been accurately described in the journals. In bore No. 12 Balderston, a coal, 4 ft. thick, was met at a depth of 13 fms., and in bore No. 11 Balderston, a coal, 3 ft. 10 in., at 8 fms. It is probable that the coal in each bore belongs to one seam, and is higher in position than the seam mined in the old pit, but thick beds of volcanic ash occur in the vicinity, and the geological structure is far from clear.

Various bores put down near the north-west end of Linlithgow Loch have pierced alternating bands of igneous and sedimentary rock, the latter of subordinate thickness, but containing various coals, some of which may represent the Red Coal, Six-feet, East Main, and Smithy seams, which were formerly worked in the old mine near Upper Bonnytoun. It is not possible to correlate individual seams with confidence, but a seam of foul coal, 2 ft. 10 in. thick, which was found at a depth between 62 and 63 fms. in the bore No. 1 Lochhouse (about 300 yds. N.N.E. of Loch House), is generally considered to represent the Red Coal. In bore No. 1 Parkhead (300 yds.

south-east of Parkhead) a foul coal, 2 ft. thick, at a depth of 34 ft., is perhaps in the position of the Smithy Coal.

The boring No. 6 Kinneil, put down near the Little Mill, three-quarters of a mile W.N.W. of the west end of Linlithgow Loch, affords evidence that, in this locality, the volcanic rocks increase in thickness for a certain distance in a westerly direction—towards the dip—and that, concurrently, the coals die out or become valueless. The bore starts in a volcanic ash some distance below the Index Limestone, and is 691 ft. deep. The first sediments met with, at a depth of 490 ft., are perhaps on the horizon of the Wester Main Coal, but they include no coal and are only 7 ft. thick. The rocks pierced below this are evidently to a large extent of igneous origin and do not comprise a single coal seam.

In hope of finding the Bo'ness coals in good condition on the western side of the Kinneil workings, Messrs. W. Baird & Co., of Bothwell Collieries, have lately made a deep boring near North Hainings, in a position rather more than a mile W.S.W. of the deepest part of the Kinneil Collieries. The results are most disappointing. The bore enters the Index Limestone at 45 fms. and proceeds to a total depth of 425 fms. The position of the Seven-foot Coal is recognisable at a depth of about 32 fms. below the Index Limestone, but below this point there is an abnormally large proportion of whinstone and volcanic ash. The characteristic roof of the Smithy Coal was not recognised, but it seems certain that the whole of the rocks representing the position of the Bo'ness Coal group was pierced, for, at 394 fms. a limestone, 15 in. thick, is recorded, the core of which is a dark grey limestone of good quality and includes fragments of crinoid stems. A higher bed, at 268 fms., is also recorded as a limestone; it is a foot thick, surmounted by 22 in. of calcareous calm and fakes, and was described by the borer as a blue limestone.

C. T. C.

Upper Limestone Group.

Woodmuir and Foulshiels area (Sheet 31).

At the south-east corner of Sheet 31, the Index Limestone is never seen at the surface, but between Woodmuir fault and Mosshall its position has been traced by numerous bores. It is usually about 4½ ft. thick and is overlaid by blaes and balls, from 12 to 18 ft., succeeded by a thick white sandstone. A quarry was opened three-quarters of a mile south of Breich Station in the upper portion of this sandstone, but the rock proved to be inferior and soft, with a peculiar concretionary structure. Between the Woodmuir and Leven Seat faults the position of this limestone has not been proved.

The Arden (Gair) Limestone is reported to have been wrought in a small quarry at the cross roads west of Hendreys Course, but the excavation is now grassed over, and this limestone has not been recorded in any of the bores to the north where it might have been expected to occur.

For over two hundred years the Castlecary (Leven Seat) Lime-

stone has been wrought on the east side of Leven Seat. At first the workings were open-cast, and latterly the stone was mined. The underground workings extend for half a mile to the west of the cairn.

This limestone is about 9 ft. thick and is overlain by an oil-shale 15 in. in thickness, of excellent quality, which was mined with the limestone. For many years before the advent of the oil-shale industry this tough leathery shale was sold throughout a wide area and used for cover plates for road culverts, and although less than one foot thick these plates can carry a heavy traction engine. When paraffin oil was first produced from oil-shale, this seam was retorted and the oil refined near Greenburn, and latterly the crude oil was sold to some of the larger refineries. In the mined area the limestone was best at the outcrop, and continued good till it was covered with from 20 to 24 fms. of strata. At this depth it became rapidly poorer in quality and also thinner, probably owing to partial solution by percolating water.

On the north side of the Bank Head fault this limestone is only represented by a band of thin limy shale below a sandstone roof, but its position has been determined by the outcrop of the Curly Ironstone which lies 8½ fms. above it. At Blackhill, Breich Water, a grassed-up quarry with kilns doubtless indicates the outcrop of the limestone, and from this point to Mosshall its position has been determined by protraction from known outcrops. J. S. G. W.

THE BATHGATE AREA (Sheet 31).

Between the river Almond and Durhamtoun there is very little accurate information about the Upper Limestone group as a whole, though the lower portion, including the Index Limestone, has several times been passed through in search of the underlying coals. It is interesting to find, however, that the oil-shale, overlying the Leven Seat Limestone in its typical district, has been proved by boring near Durhamtoun, though in an unworkable condition. Northwards again between Durhamtoun and Hilderston, while there are several deep bores traversing the whole of the group, there is only a single surface exposure of any portion of it. This occurs in a cutting of the mineral railway leading to the Balbardie Colliery, where the Index Limestone, 3 ft. thick, is seen to contain *Productus latissimus* and other shells, and to be overlain by 15 ft. of grey fossiliferous shale passing upwards into faky sandstones, which also in their bottom layers contain casts of *Productus* and other marine organisms.

The deep bores alluded to, which occur in the Bathgate district, prove two points of importance, first, the presence of a volcanic horizon between the Index and Calmy (Arden) Limestones; and, secondly, the rapid variation in thickness of the group. The four chief bores are as follows: Walker's Bore at Little Boghead—Vivian's Bore starting a little above the base of the Coal Measures, slightly south of the Bathgate fault, less than half a mile west of Walker's Bore—Easton Bore, slightly over half a mile N.N.W. of Vivian's Bore—and Hilderston Farm Bore, a mile and a quarter

N.N.E. of the Easton Bore. An abstract of these bores is given in the following table:—

	Walker's.		Vivian's.		Easton.		Hilderston.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Leven Seat Limestone ..	5	9	7	1	4	6	4	2
Strata	170	0	247	0	158	0	139	0
Calmy Limestone	4	2	5	6	4	0	1	6
Strata with Whinstone ..	288	0	?		480	0	297	0
Index Limestone	4	4	—		4	0	4	11
	472	3	—		650	6	446	7

The 80 ft. of increase between the Leven Seat and Calmy Limestones in Vivian's Bore, as compared with Walker's, is due to an expansion of the shaly portion of the series and not to the development of grits or sandstones. It should be stated also, that Vivian's Bore went down 747 ft. beneath the Calmy Limestone without reaching any recognised representative either of the Index Limestone or the seams of the coal-bearing group. Considering the position of the bore, and its great depth, it seems probable that it passed through the Bathgate fault, and that the Index Limestone and the underlying workable coals have thus been cut out of the section which it traversed. The proportion of "whin" proved in Vivian's Bore is certainly too small to account by itself for the absence of the limestone and coals from the bore record, and if the Bathgate fault has not been pierced, it is necessary to regard the whole thickness as belonging to the Upper Limestone group—an unlikely interpretation. At all events it would be unwise to be deterred by the result of this bore from further exploration of the field underlying the Coal Measures.

The following details are taken from Walker's Bore:—

	Ft.	In.
Leven Seat Limestone	5	9
Blue blaes..	2	9
Kingle stone	0	6
Light faky fireclay	17	10
Sandstone..	16	6
Fakes	39	1
Sandstone with kingle rib near middle	37	6
Fakes and blaes	56	3
Arden or Calmy Limestone	4	2
Sandstone..	11	8
Grey fakes	14	10
Sandstone..	7	3
Kingle	1	5
Grey fakes and hard ribs	26	8
Sandstone..	11	4
Fakes and hard ribs	17	10
Fakes and sandstone	12	7
Whinstone, soft above	36	6
Dark grey fakes	4	8
Carry forward ..	325	1

	Ft.	In.
Brought forward ..	325	1
Whinstone	40	1
Dark fakes	2	4
Coal, foul	0	4
Bands of sandstone, fakes and blaes	81	6
Blue blaes	19	0
Index Limestone	4	4
	472	8

E. B. B.

HILDERSTON TO COCKLERUE (Sheet 31).

The Index Limestone is at present exposed at the top of a small quarry on the west side of the road, and half a mile east of Hilderston Farm. The section is as follows:—

	Ft.	In.
Argillaceous limestone in bands, with *Productus latissimus* ..	3	6
Blaes..	4	0
Coal	1	0
Fireclay and shale	6	0
Sandstone and shale	5	0
Coal	1	3
Sandstone, base not seen	10	0

In quarries on the east side of the road, two other thin coal seams are exposed.

The section given above is the only exposure of the Upper Limestones until we reach the old workings of the Castlecary Limestone at Lochcote. This limestone has been wrought on the north side of the Kipps dyke, but, on its south side, the great Torphichen sill transgresses to a lower horizon and prevents the outcrop of the Castlecary seam. The outcrop of the Arden Limestone is not known south of Carribber Glen. H. B. M.

COCKLERUE TO LINLITHGOW (Sheet 31).

The Index Limestone is best seen in the Avon north of Linlithgow Bridge, where the following section occurs, the lowest bed of which has already been described:—

	Ft.	In.
Sandy shale		
Limestone	0	6
Shale with fossils	3	0
Limestone	2	6
Shale	2	0
Coal	0	3
Ash		

Productus latissimus is very abundant both in the limestone and in the fossiliferous shale, in which it occurs in the position of growth. This bed is not seen at the surface between the Avon and Cocklerue, but it has been recorded in bores both at the Avon Mills and near the road, 150 yds. west of Linlithgow Bridge. About 300 yds. south-west of Manuelhaughs a bore, after passing the Arden Limestone, traversed a section very similar to that of the second

bore mentioned above, agreeing in the position of several small coals, the characters of the beds between these seams, the thickness of a bed of "whin" and the distance between it and the main "whin" below. If the correlation of the rocks that seem to correspond in the bores is correct, the Index position has been passed in the bore near Manuelhaughs without any limestone being recorded.

Farther south the Index Limestone probably sweeps to the south-east, parallel to the next higher limestone, being recorded close to the surface in a boring at Belsyde, and also the one reported to have been found a quarter of a mile north of Cocklerue, below dolerite which was quarried for the reservoir close by; from here it strikes southward with the associated sandstones, ashes and lavas, which occur above it.

The strata above these lavas consist chiefly of sandy shales and some fireclays. In the Avon gorge east of Muiravonside, as we approach the Arden Limestone, some ashy sandstones are found which have yielded the following fossils: Cup corals, *Productus*, Orthotetid shells, *Fenestella, Orthoceras* and Trilobites.

The Arden Limestone is well seen in the Avon at Woodcockdale, where it is repeated by a small fault; here it overlies some plant-bearing shales, and, as at Carribber Glen, occurs in several bands with shaly partings between.

At Easter Carribber the following section of the limestone is seen on the south side of the glen:—

	Ft.	In.
Dark sandy shale		
Impure limestone	0	6
Shale	0	6
Compact limestone	3	0
Shale parting		
Limestone	0	8
Shale		

The limestone is an impure, dark-blue pyritous bed giving a white surface on weathering. Though the outcrops are few, its position has been defined by borings west of the Avon. In Carribber Glen at least 50 or 60 ft. of dark-blue shale rest directly on the limestone; on the north bank of the river these shales are again seen, but the limestone itself has not been noticed in place. North of the Canal aqueduct, beds in this position become more sandy.

The uppermost limestone of this series, the Leven Seat or Castlecary, is well exposed in the Avon, just below the Canal aqueduct, resting on sandy shales and surmounted by sandstone. It occurs in several distinct bands, with a total thickness of 5 ft. and is very dolomitic, hardly effervescing with acid, while its specific gravity is 2·90 and indicates the presence of some iron. It is not now seen in Carribber Glen, but the old quarries on the south side indicate its position. On the north bank a good section of the strata above the blue shale overlying the Arden Limestone can be seen, but the dolerite intervenes before the topmost limestone is reached. From the glen southwards the outcrop is well marked by old workings as far as Bowdenhill, where the limestone is about 7 ft. thick, almost

black, crinoidal and effervesces freely *—in strong contrast to its behaviour only a mile farther north. G. W. G.

LINLITHGOW TO BO'NESS (Sheet 31).

In this area the group includes, besides the Index, the Arden (Calmy or Dykeneuk) and the Castlecary (Leven Seat) Limestones, another band (between the Index and Arden) which will be called the Kinneil Mills Limestone. From evidence obtained from bores the total thickness of the group appears to be about 830 ft.

The Index Limestone is exposed on the west side of the Avon, west of the Little Mill, and in various places at the sides of the stream that joins the Avon from the north a quarter of a mile north-west of the Mill. It averages about seven feet in thickness, including various bands of calcareous shale, and is characterised by the abundance of *Productus latissimus*. At the base there is a calcareous mudstone about a foot thick, with a somewhat ashy aspect in parts, which contains abundant remains of *Fenestella*, but very few of *Productus*, and, below this horizon, there is a coal about seven inches thick. In one of the exposures, a band near the top also seems somewhat ashy.

In the cliffs behind the Bo'ness Distillery the section is somewhat as shown below:—

	Ft.	In.
LIMESTONE	2	3
Calcareous shale	0	9
LIMESTONE	1	0
Crinoidal shale with small nodules of limestone	3	0

The exposures in these cliffs are imperfect and have not provided many fossils, but some blocks, which were formerly removed from this locality to a field near Kinneil Railway Station and are now considerably weathered, are seen to be full of *Productus latissimus*.

At the distillery a bed of shale, about eight feet thick, comes above the limestone, and is in turn overlain by a sandstone, which in the Snab Pit (No. 1) shaft is 79 ft. in thickness. This sandstone is exposed at the back of the 20-ft. raised beach west of the distillery, and is a good building stone, largely wrought in the Maiden Park and Deanfield quarries, etc. In the same shaft just below this thick sandstone a bed of fireclay was formerly extensively mined for making firebricks; and, about 14½ ft. above the sandstone, a coal, sometimes called the Mount Hunger Coal, is recorded, 2 ft. 3 in. thick, including a 3-in. shale parting near the middle.

Near the Avon the thickness of the strata, including a band of igneous rock that probably represents a lava flow, between the Index Limestone and the Kinneil Mills Limestone is probably about 250 ft., but near the Forth the thickness seems greater, for the journal of the North Hainings boring, already alluded to, shows a limestone 22 in. thick, which appears to represent the Kinneil Mills bed, and is 375 ft. above the top of the Index.

* It is also remarked by Charles Forsyth (*Trans. Highland and Agric. Soc. Scotland*, 1846) that on account of its freedom from magnesia it is particularly suited for agricultural purposes.

The Kinneil Mills Limestone is only exposed in one place, on the north side of the Avon about 100 yds. west of the bridge at Kinneil Mills, where it is crowded with *Productus latissimus* and has a considerable resemblance to the Index Limestone, but it is only 3 ft. thick—hardly half as much as the Index Limestone at the Little Mill—and rests almost directly on an 8-in. coal seam. There is no bed below it like the shale with *Fenestella* which occurs below the Index. In a boring put down at the roadside about 400 yds. E.N.E. of Dykeneuk, a limestone, 22 in. thick, including a 7-in. parting of blaes, was met at a depth of 17 fms., and probably represents the Kinneil Mills Limestone. It is too near the surface to be the Index, for the bore appears to start in beds only about 200 ft. below the Arden Limestone, and in the North Hainings Bore the interval between the Arden and the Index Limestones is as much as 578 ft.

A few feet below the Arden (Calmy or Dykeneuk) Limestone, a coal, called either the Wood Coal or the Upper Hirst or the Janet Peat, has formerly been extensively worked in shallow pits near Dykeneuk and in Kinneil Woods (whence the name "Wood Coal" is said to be derived). On the south side of the railway line, 250 yds. east of Dykeneuk, this coal is exposed. It is at least 2 ft. 8 in. thick, and lies about 20 ft. above another rather thinner coal. In the journal of bore No. 1 Kinneil, put down about 300 yds. south-west of Dykeneuk House, the Wood Coal is described as a foul coal 24 in. thick, and the underlying "soft" coal is 18 in. thick. In the journal of No. 5 Kinneil Bore, 300 yds. north of East Kerse Mains, the Wood Coal is described as a good coal 3 ft. thick.

The Arden Limestone was formerly extensively worked near Dykeneuk, along the outcrop south of the railway and in day levels. It is not exposed in this locality now, but in the boring just referred to the following section was found:—

	Ft.	In.
Dark blue blaes	19	2
LIMESTONE	1	8
Blue blaes	1	11
LIMESTONE	1	8
Soft blaes	0	7
LIMESTONE	1	0
Blue fireclay and blaes	3	1

This limestone is seen in the Avon in three places, between half a mile and a quarter of a mile west of Kinneil Mills, once on the north side of a powerful east and west fault, and twice on the south side and considerably disturbed. The fault throws down to the north and is no doubt a continuation of the dislocation which crosses the river 300 yds. above the viaduct. None of the exposures are complete, but the bed is evidently of good quality, about six or seven feet thick, and overlain by a considerable band of shale, at least 40 ft. in thickness, containing various thin calcareous seams and lenticles. In the North Hainings Bore the distance between the Arden Limestone and the thin limestone that is supposed to represent the Kinneil Mills Limestone is about 188 ft., and the former bed is 7½ ft. thick, including two shale partings.

A boring, No. 3 Kinneil, put down 650 yds. W.S.W. of East Kerse Mains, proved the strata which there intervene between the Arden and the Castlecary Limestones to be more than 240 ft. thick. Some distance above the shale overlying the Arden we find a thick rather coarse-grained massive yellow sandstone, which has been quarried at the roadside near North Hainings, and is also well seen in the Avon.

On the south side of the railway line, about a quarter of a mile south-west of Dykeneuk, a peculiar ferruginous calcareous sandstone, about a foot and a half thick, occupies perhaps a nearly middle position between the Arden and the Castlecary Limestones.

The Castlecary (Leven Seat) Limestone is not now well exposed in any part of this district, but it was formerly extensively mined near the coast at Craigenbuck (300 yds. S.S.W. of North Hainings) and also 150 yds. east of the Avon viaduct. The following section is recorded in the last-mentioned locality:—

	Ft.	In.
LIMESTONE, grey crystalline	4	4
Shale	0	6
LIMESTONE, concretionary	1	1
LIMESTONE, compact blue	1	1
Shale, blue and dark grey	6	0
Shaly sandstone and dark shale	4	0

Part of the bed now visible near the Avon is coarsely crystalline and evidently dolomitic, having a specific gravity of 2·86. In the railway cutting a quarter of a mile S.S.E. of North Hainings the limestone is also exposed, dipping nearly north, probably under the influence of some fault, and is again dolomitic with a specific gravity of 2·81. The underground workings near the Avon extended 600 yds. north-east from the outcrop on the north side of the river, and the bed probably extends considerably farther in this direction before it curves and strikes north-west or west, under the influence of the fold which is indicated a little east of Dykeneuk.

In the Avon the general inclination of the beds is north of west, often at angles varying between 10° and 20°, and for some distance to the north the crops of the beds must run north-east, but south-west of the Little Mill the dip of the sediments is south-west, and the strata near the thick volcanic ash must be rather sharply bent. The southerly dip on the west side of the locality where we find the change of strike referred to in the preceding paragraph is well seen in the steep bank at the back of the raised beach, and continues nearly to East Kerse Mains, where the inclination is south-west. For about a quarter of a mile west of this farm the dip appears to continue south-west, after which we enter an area with varying dips, which is perhaps crossed by some important faults. The exposure of the Castlecary Limestone in the railway cutting near North Hainings is perhaps near the north side of a fault with a considerable downthrow to the south, for it is inclined to the north, and the beds farther south should be lower in the stratigraphical sequence if such a dip continued without any faulting. In a boring, however, put down near the railway 700 yds. farther south, this limestone was again found at a considerable depth.

In an old boring put down in the Willow Bog—the alluvial land

about 170 yds. south of Inveravon—the base of a limestone, 5 ft. 7 in. thick, was found at 32 ft. This band, overlain by 17 in. of limy fakes, probably represents the Castlecary Limestone, and, to account for its high position at the Willow Bog, it seems necessary to suppose that it has been thrown up to the north by a fault of considerable amount, perhaps about 100 ft., which may pass through an obscure area a little south of the old boring. The supposed fault may continue in an E.N.E. direction past the south side of the limestone outcrop in the railway cutting.

In boring No. 5 Kinneil, 300 yds. north of East Kerse Mains, the base of the Arden (Dykeneuk) Limestone was found at a depth of 140 ft. (and 64 ft. below the rock surface). The beds exposed near East Kerse Mains are considerably above this limestone in the stratigraphical sequence, but it is considered probable that the limestone comes to the surface about half-way between the farm and the site of the bore, dipping south or south-west like the other beds exposed in the locality. It seems probable, therefore, that a fault with a considerable downthrow to the north passes between the site of the bore and the farm: the direction of the supposed fault is very doubtful, but in the map it has been drawn W.S.W.

C. T. C.

Carboniferous Volcanic Rocks of the Bathgate, Linlithgow and Bo'ness District.

The volcanic rocks now to be described are confined to that part of the Lower Carboniferous formation which occurs near the line of junction of the one-inch maps 31 and 32, in western Linlithgowshire, and the adjoining parts of Stirlingshire. Most of them are within the limits of the Carboniferous Limestone series, and it is worthy of note that in Mid-Lothian there is no trace of contemporaneous igneous activity in this division of the system. It is quite possible that a larger proportion of intrusive rocks is associated with the lavas than is represented on the maps, for some of those recognised as intrusions are of much the same petrological type as lavas, and the lack of natural exposures often prevents the determination of the relations between the igneous and the adjoining sedimentary rocks.

Various modifications of Sir Archibald Geikie's original mapping and descriptions of the district have been made, but few are of more than local importance. The most noteworthy consists in the detection of an intrusion of quartz-dolerite which traverses the hills in a north and south direction. Dr. Falconer had recognised this feature previous to the commencement of the recent revision, but his results were not made public until 1905,* by which time they had been confirmed by the independent mapping of the Geological Survey. This point will be referred to again in Chapter XV. It is interesting also to note that evidence has been obtained pointing to the conclusion that the Bo'ness lavas form a portion of the Bathgate belt, so that the latter does not end at Linlithgow as originally supposed.

C. T. C.

* "The Igneous Geology of the Bathgate and Linlithgow Hills," *Trans. Roy. Soc. Edin.*, 1905, vol. xli. p. 359.

BATHGATE TO COCKLERUE (Sheet 31 in part).

The volcanic rocks of the Bathgate Hills attain their greatest development about two or three miles south of Linlithgow. It will be convenient to take a general section from east to west along this line (see Fig. 11) as the basis of our description, and to note the changes which affect the various groups of lava and tuff, first as they are traced southwards and then as they are followed northwards.

The period of vulcanicity commenced in late Calciferous Sandstone time with the accumulation over an extensive area of a bed of green and red tuff at a definite horizon a few feet above the Two-foot Coal (2, Fig. 11). From Drumcrosshall the tuff forms a well-marked band traceable almost to the shores of the Firth of Forth, a distance of over six miles, whilst its former eastward extension is proved by its occurrence in a synclinal basin of the oil-shale field at Little Ochiltree. The tuff is overlain by shales and sandstones, followed in Longmuir Plantation by a thin bed of green tuff and then by several flows of basalt (3, Fig. 11). The lowest of these, exposed in a small quarry on the south side of the east and west dyke, is a dark compact olivine-basalt of Dalmeny type and exhibits a well-marked columnar structure. The other outcrops show only decomposed and vesicular basalts, which dip beneath a thick series of shales and sandstones exposed in the quarry above Broomyknowes (where a thin seam of coal also occurs) and at intervals along the eastern slopes of the Riccarton Hills. They have a westerly dip of 10° to 15° and pass below the great mass of lavas, which forms the greater part of the Hills (4, Fig. 11). The individual flows, of which there are perhaps eight, may be separated in some degree by means of the little hollows formed by weathering along the line of junction of the vesicular top of one flow with the vesicular base of the succeeding one, and by the two intercalated beds of sandstone (5, Fig. 11). One of these lies on the north shoulder of the Hills south-west of Broomyknowes, whilst the second occurs in small artificial exposures situated between outcrops of basalt 400 yds. south-east of Beecraigs. The lavas are all very much of one type, dark, compact olivine-basalts, but the second flow from the base is coarser-grained and more felspathic. Olivine nodules were noticed in the topmost basalt at the outcrop beside the stream about 200 yds. north-west of Beecraigs. Northwards the whole series rapidly thins out and disappears, but to the south the thinning takes place much more

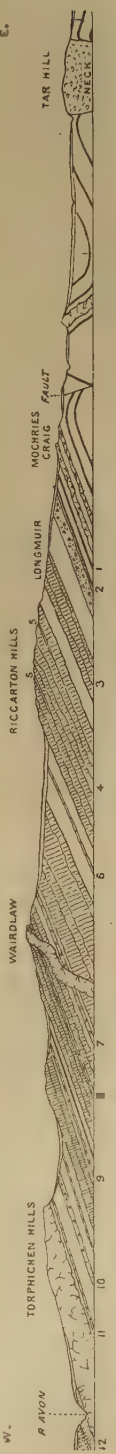

FIG. 11.—General Section across the Volcanic Rocks of the Bathgate Hills. 1, Houston Coal; 2–12, see explanation in text.

slowly and seems to be brought about by the upper members alone dying away. The shales and sandstones at the base of the group thin out, so that, south of the Mains Burn, the Riccarton Hills and Longmuir lavas come together. Although the group is thinning away the outcrop remains broad owing to slight local folding, which results in the strike taking on an east and west direction in the neighbourhood of Quartèr. The basalt situated to the north-east of Drumcross is an outlier of this zone faulted down in a shallow syncline against the tuff above the Two-foot Coal. To the southward, in Sheet 31, a bed of tuff exposed near Wester Drumcross and at Whitelaw is intercalated amongst the basalts, whilst smaller and apparently lenticular layers appear at a higher horizon in the wooded hollow east of Kirkton Lime Works. In the section in the Almond River to the south of Bathgate, the whole volcanic series of the Bathgate Hills has disappeared with the exception of a bed of tuff, which is proved to lie 140 ft. above the Raeburn oil-shale, and may well be on the horizon of the Whitelaw tuff.

The sediments overlying the Riccarton Hills lavas include the Tartraven Limestone (6, Fig. 11). In their southward prolongation into Sheet 31 they are largely replaced by basalt flows, marked off at the bottom and top respectively by the East and West Kirkton Limestones. H. B. M.

The interesting section in the East Kirkton Quarry was first described by Dr. Fleming,* who noticed some of its more peculiar features, but it was more fully and accurately dealt with by Dr. Hibbert † and Sir A. Geikie.‡ The latter enters into great detail, and his account is virtually followed here, but there is no important difference between the views expressed by the two authors.

The general section in the quarry is as follows: The floor is ash resting on basalt; above this come various limestones with ashy seams intermingled, then shales and ashy sandstones, while the whole is surmounted by basalt, forming the crest of the quarry. The subjoined woodcut gives a detailed section of the north end of the quarry.

The lowest bed is a loose pulverulent concretionary ash (*a*), resting on basalt; above it comes a thin irregular band of ash-beds and ashy limestone. A very unequal stratum of limestone (*c*) succeeds; at one point it measures 6 ft. in thickness, while a short way off it increases to 13 ft. It is a hard, grey, cherty rock, the chert being either arranged in fine laminæ, curiously contorted, or in an irregular brecciated or nodular manner. At the present time the contorted beds are not well exposed in the quarry, but they may be studied to advantage in the walls of the neighbouring fields. The limestone is further noteworthy as having yielded several remarkable specimens of *Eurypterus scouleri*, named and described by Hibbert. Various alternations of ash and limestone occupy the remainder of the section (*d* to *i*) until a mass of herbage and debris obscures the slope. Above this we again meet with a limestone (*k*), finely laminated, very fissile and containing remains of entomostraca;

* "On the Neptunian Formation of Siliceous Stalactites," *Edin. Journal of Science*, April 1825, p. 307.

† "On the Fresh-Water Limestone of Burdiehouse," *Trans. Roy. Soc. Edin.*, 1836, vol. xiii. p. 169.

‡ "The Geology of the Neighbourhood of Edinburgh," *Geol. Sur. Mem.*, 1861, p. 49.

some of the laminæ show a mammillated surface, while others have undergone great twisting and contortion. Black shales and sandy beds (*l* and *m*), somewhat ashy in the upper part, next supervene. During the first survey numbers of beautifully preserved plants, including *Lepidodendron, Stigmaria* and *Pecopteris*, were discovered in some of these beds, but the richest fossiliferous horizon does not appear to have been found during the late revision. The following plants were, however, collected by Messrs. Kidston and Tait, and determined by Dr. Kidston,—*Sphenopteridium crassum* L. & H. sp., *Adiantites*, sp.*

A bed of columnar basalt (*n*) of the Dalmeny type completes the section, and, though the evidence is not conclusive, there are appearances suggesting that the base of the igneous rock transgresses the underlying black shales. It may, therefore, be a sill like that of the Hillhouse quarries.

Both Dr. Hibbert and Sir A. Geikie referred the remarkable series of deposits underlying the basalts to the operations of geysers or thermal springs supplying a restricted lagoon, and the physical and palæontological features noticed above, accord well with this interpretation. No satisfactory explanation has, however, yet been offered regarding the remarkable contemporaneous contortions of the laminated cherts and limestones.

Fig. 12.—Section in East Quarry, Kirkton (after Sir A. Geikie).

E. B. B.

Returning to Tartraven we find the shales above the limestone succeeded by a series of basaltic flows, which are exposed in sections beside the road right up to the position of the Petershill Limestone (7, Fig. 11). The lowest lava appears as a thin decomposed amygdaloidal basalt overlain by a thicker sheet exposed in quarries at Mid-Tartraven. The latter is an analcite-bearing basalt, with a well-developed horizontal platy jointing parallel to the fluidal texture of the rock, surmounted by a weathered brecciated crust. After passing over a few crops of weathered basalt, which may indicate another flow, we reach a dark compact, columnar olivine-basalt, which extends up to the position of the Petershill Limestone.

This group of lavas dies away rapidly to the north, and is represented by a bed of tuff, which is first seen near Balvormie.

* The type of *Sphenopteris Hibberti*, L. & H. ("Fossil Flora," 1836, vol iii. p. 73, plate clxxvii.), also came from a "deposit of fresh-water Limestone occurring at Kirkton near Bathgate."

Southwards the outcrop is obscured by boulder clay until the Knock is reached, when knobs of columnar basalt again appear. In this district the group is capped by a bed of tuff which lies at the base of the Petershill Limestone.

The great mass of basalts that overlie the Petershill or Silvermine Limestone, lie on the whole beneath the Bathgate Coal group. In the district around Cocklerue, however, where they reach their greatest development, the coal group is replaced by lavas, which thus separate the Bathgate Coal-field from that of Bo'ness. The lowest portion consists of vesicular basalts; then follow, near Craigmailing (Sheet 31), tough, black, compact, olivine basalts, sometimes with nodules of augite and usually exhibiting a well-developed columnar structure. Above these again lie three or four flows of dark blue amygdaloidal basalt, forming terraces on the hill slope.

The position of the local limestone of Wairdlaw amidst these basalts has already been pointed out (p. 111), (8, Fig. 11). Above the limestone the lavas are exposed in isolated crops of fine-grained, dark blue, columnar basalt intermingled with crops of decomposed vesicular rock, which are probably the slaggy surfaces of the different flows. In a roadside quarry 700 yards south of Kipps the rock (a Hillhouse basalt) contains numerous nodules of augite sometimes more than an inch long. This group of lavas may be followed southwards along the crest of the Bathgate Hills. South of the Knock the individual flows become separated by sediments, which form hollows between the lava ridges.

The Bathgate Coal group having the Index Limestone at the top succeeds next to the west (9, Fig. 11). At Haddies Walls and again at Hilderston Hills outcrops of dark bluish basalt probably indicate isolated flows of basalt amongst these sediments.

Above the position of the Index Limestone there follows a well-marked belt of volcanic rocks. A green basaltic tuff which lies at the base of this group, near Cocklerue, dies out to the south of Kipps. It is succeeded by a series of dark basalts, which often show a well-developed columnar jointing. It is possible, to judge from certain indications in the field, that the columnar rock of Kipps Hill is intrusive, but so far as regards the Carboniferous basalts, the possession of a hexagonal columnar jointing is so frequently a character of unquestionable lavas that it cannot, in this instance, be accepted as evidence to support the suggestion. An obviously interbedded lava possessing a vesicular and pillowy upper and under surface may have a columnar central band, a phenomenon clearly exposed over and over again in the Fife coast sections.* It is very probable that the vesicular basalts, such as those cropping out around Kipps Hill, are only slaggy surfaces of flows which are columnar in their central portions, and as the columnar rocks have the same petrographical character as the non-columnar ones, they are retained amongst the lavas.

Proceeding southwards the basalts crop out again around Cathlaw House, but except for some small openings near Bishopbrae, the lavas are not again exposed at the surface. They are,

* "The Geology of Central and Western Fife and Kinross," *Geol. Sur. Mem.* 1900, p. 53 *seq.*

however, proved by the bores already quoted (p. 138) to extend southwards for some distance beyond Bathgate.

The above group practically marks the close of active vulcanicity in the district. A thick bed of green tuff (10, Fig. 11), which may lie above the position of the Arden Limestone, is exposed in the wooded glen south of Lochcote Reservoir, and ashy material may be found mixed in the sandstone close up to the Leven Seat Limestone, but there seem to have been no further outpourings of basalt.

The volcanic history of the Bo'ness and Bathgate Hills may be compared with that of Fife. The lavas associated with the Calciferous Sandstones and Lower Limestones of the Kinghorn district correspond to those extending from the Riccarton Hills to a position above the Wairdlaw Limestone, whilst the volcanic outbursts of the Saline Hills cover the time occupied by the accumulation of the lavas and ashes, which lie above the Index Limestone in the Bathgate Hills. H. B. M.

COCKLERUE AND BROOMYKNOWES TO LINLITHGOW (Sheet 31 in part).

Returning again to the base of the volcanic series to the south-east of Linlithgow, we find the tuff above the Two-foot Coal in the bank of a stream, half a mile west of Wester Ochiltree. The tuff at first sight appears coarse, containing great rounded masses, but these, when examined, are found to be calcareous concretions. The position of its outcrop northward in the direction of Haugh Burn has already been described (p. 101). G. W. G.

The same bed of tuff is exposed about three miles to the north-east on the north side of the Midhope Burn at Binns Mill, where it occurs above the Two-foot Coal and not far from the volcanic vent of Binns Hill.

An outlier of this tuff occurs in a faulted synclinal basin between Little Ochiltree and Three Miletown. The tuff lies above the Houston Marls and is only exposed at a few points. It is a purplish, sandy tuff with numerous black shale fragments. The dip is irregular and the underlying coal (the Two-foot) is not seen.

J. S. G. W.

The lavas of Longmuir Plantation are last seen in a northward direction 500 yds. south of Riccarton. They appear to be on the horizon of the Riccarton limestone bands.

The farm of Broomyknowes stands at the base of another larger series of lavas, which form the main mass of the Riccarton Hills. Several flows can be made out in the stream north-west of the house, the lower ones being coarse, decomposed, and marked by small geodes lined with chalcedony, on which crystals of quartz have grown. Fresher material representing this part of the series may be got from a good exposure about 30 yds. north-west of the farm. The specimen sliced (11979) is classed by Dr. Flett under the Gallaston type. Rather finer-grained basalts appear in the stream section 300 yds. west of Broomyknowes.

The basalts and fragmental rocks associated with the Lower Limestones of the Carboniferous Limestone series have at their base a band of ash which, as already mentioned (p. 112), continues

to the neighbourhood of Hiltly, where it is intermingled with lava flows among which it is not traceable and may die out. Farther north the flows begin to wedge out until we find only 35 ft. of "whin" in the St. Magdalene Distillery well. An horizon of igneous activity extends from the bed of whin below the position of the base of the Bo'ness and Bathgate Coal group up to the Index Limestone, which immediately overlies this group, but here and there intercalations of sediment and beds of fragmental material occur. One of the best of these can be seen in the stream W.N.W. of Preston House, where a band of fine grey ash, about 50 ft. thick, is surmounted by a few feet of shale and sandstone, upon which rests a columnar basalt lava flow, compact at the base and with indurated sandstone below for 4 or 5 inches, with a glassy appearance on fractured surfaces.

These lavas occupying the position of the Bo'ness and Bathgate Coal group are usually dark compact, almost flinty rocks which hardly ever show a thick crust of decomposition products. Olivine in small phenocrysts is the only constituent visible to the unaided eye. Vesicular types are seen on the road close to the Manse south of Linlithgow, where more dolerite varieties also occur. Several specimens from different horizons were sent to Dr. Flett who finds them to be olivine basalts, chiefly of Dalmeny type, together with representatives of both Gallaston and Hillhouse types; but these varieties are not characteristic of particular horizons. Hardly any evidence bearing on the mode of occurrence of the basalts is present, as the ground is largely obscured by drift through which only the massive parts project. The uppermost flows are seen at Woodcockdale in a stream by the canal; below the railway bridge in the Avon; and north of the road at Linlithgow Bridge. In this last locality they are succeeded by two bands of ash each about 20 ft. thick and separated by a 4-ft. parting of sandy shale with a 6-in. coal at its base; the lower bed of tuff is fine-grained and laminated, with structures like vesicles, which are lined in places with chalybite and contain white calcite at the centres. The phenomena can perhaps be explained on the supposition that the bed flowed as a viscous mud. The upper bed of tuff contains large fragments of lava, often 5 or 6 in. across. In the bore at the Avon Mills only one band of ash is recorded with 18 ft. of sediment between it and the main mass of lavas below, but perhaps the lower bed of ash has been mistaken for sediment or even included in the "whin" below. The tuff and lavas overlying the Index Limestone position near Cocklerue appear to thin out considerably to the north. The comparatively thin bed seen in the Avon at the Avon Mills occurs on this horizon. According to Dr. Flett's determination, it has the characters of a basalt of the Hillhouse type (11947). G. W. G.

LINLITHGOW TO BO'NESS (Sheet 31 in part).

Most of the contemporaneous igneous rocks are in the form of basaltic or doleritic lavas which are usually much decomposed, but where fresh they contain distinct blebs of olivine in many places. No general difference in character has been recognised

between the bands which occupy different stratigraphical positions within the series. The great majority of the rock specimens which have been sliced are referred by Dr. Flett to the Gallaston type of basalts and dolerites.

The lavas are mixed with subordinate bands of volcanic ash, some of which are very thick, and have probably been accumulated in the immediate neighbourhood of volcanic necks.

In the northern part of the area most of the igneous rocks occur in the Bo'ness and Bathgate Coal group, wherein they form the greater part of a middle division—the thickest of the three—which separates the lower from the upper coal-bearing beds, as already described. Farther south, however, it is clear, from various small rock exposures on the north side of Linlithgow Loch and from the evidence afforded by a considerable number of borings, that the igneous rocks are in excess of the sedimentary in the lower division of the Coal group, and are also greatly developed in the upper part of the Lower Limestone group.

Near the Forth the lowest igneous rock of which we have any certain knowledge is a thin volcanic ash, 5 ft. thick, interstratified with a thin limestone in a boring near No. 9 Pit, Grange. This limestone is hidden at the outcrop by superficial deposits, but in the bore its top is 16 ft. below the base of the Carriden Lower Limestone.

Not far above the last-mentioned tuff is a much thicker ash bed, well seen at the back of the 25-ft. raised beach near Carriden House. It occupies nearly all the interval, amounting to 50 or 60 ft. perhaps, between the Carriden Lower and Middle Limestones. It is generally well stratified, mainly composed of pieces of decomposed basic igneous rock less than half an inch long, and dips at gentle angles in the same direction, generally south or south-east, as the adjoining sediments. Some of the bands are mingled with shaly or sandy material, and the top is overlain by the Carriden Middle Limestone, which is itself mixed with some ashy material. It appears to thin out rapidly towards the west, for it is stated that the boring (made by chisel) about 100 yds. west of Carriden Church—less than half a mile from the ash outcrop—pierced no tuff, though it reached the Carriden Lower Limestone.

In the journal of a boring near Springfield the top rock, for more than 11 fms. below the drift, is recorded as fakes and fireclay, underlain by a thin impure limestone—the first of a series of three which occur near together. It seems probable that this limestone represents the Carriden Lower Limestone, and that the overlying rock is in reality volcanic ash, and a continuation of the Carriden bed.

Near Upper Bonnytoun another boring, about half a mile west of that at Springfield, pierced more than 21 fms. of whin, with more than 16 fms. of rock beneath, which is described partly as faky fireclay and partly as fakes and fireclay. It seems probable that this lower rock may also represent the Carriden ash, or a neck from which this tuff was derived. It is to be noted that it is underlain, not by limestones and sedimentary strata, like the

supposed ash at Springfield, but by lower beds of whin mixed with rocks called fireclay and fakes or faky fireclay.* The boring was continued to a depth of 85 fms. beneath the drift, and with the exception of 17 in. of hard sandstone the journal records no rock except whinstone, fakes and fireclay or faky fireclay, and it is certain that all these must be below the horizon of the Smithy Coal, which was formerly worked on considerably higher ground about half a mile to the north.

Various types of basic igneous rock, some of them with distinct olivine, and others extremely vesicular and decomposed, crop out near Walton in a rocky bank striking nearly east and west. The bank faces south and perhaps lies near the northern side of a fault—possibly a continuation of that which crosses the volcanic rocks a mile farther west with a considerable downthrow to the north. These rocks were formerly mapped as parts of a broad east and west dyke, but none of them are quartz dolerites, and two (808, 11758) are referred by Dr. Flett to the Gallaston type of dolerites. Their stratigraphical position is doubtful, but they probably lie between the Smithy Coal and the Carriden ash—considerably below the level of any of the lavas that are known farther north-east near the shore of the Forth. At the old mine north of Upper Bonnytoun, whinstone is said to occur almost immediately below the Smithy Coal, and a third of a mile south-west of Upper Bonnytoun a basic vesicular rock is exposed, probably on a slightly lower horizon.

In the northern part of the area, the middle division of the Coal group, consisting largely of volcanic rocks, comes between the Red Coal and the seam of the Upper Parrot and Ironstone. This division generally exceeds 500 ft. in thickness, and more than half of it is usually composed of igneous rocks—all apparently in the form of lava flows except one thin band of ash, which was formerly observed by Mr. Cadell at the base of the division, just under the lava that crops out about half a mile E.S.E. of Bo'ness Railway Station. Owing to the scarcity of exposures it is impossible to trace the different flows far in the field, nor is the plane between two consecutive flows usually recognised underground unless it is accompanied by some layer of sediment. It seems probable, however, that the average thickness of individual flows is not great, for thin streaks of altered sediment are often found within them either steeply inclined or at low angles. In some cases these streaks have probably been formed near the upper surfaces of flows, in cracks produced shortly after the solidification of the lava, but in others they may have been rolled along with the lava while it was still in a state of flow.

The bottom lava which comes above the Red Coal is well seen in the following localities: in the southern suburbs of Bo'ness where it forms a series of small scars striking slightly north of west; on the eastern side of the hill† with the monument, situated 1167 yds. north-west of Upper Bonnytoun; and in two places, near the

* H. M. Cadell in his "Notes on the Volcanic Rocks of Borrowstounness," *Trans. Edin. Geol. Soc.*, vol. iii. p. 304, regards all the rocks in this boring as volcanic ash. The distinctions made in the bore journal are unsatisfactory, particularly as some of the whin is described as soft and light. He states that the borer identified a piece of decomposed Carriden ash with some of the rock bored.

† Usually called Bonnytoun Hill, but not named on the one-inch map.

shore, on the north side of the big east and west fault with down-throw to the north, which passes about half a mile south of the seaward end of Bridgeness Pier.* This bottom bed is only 2 ft. thick in a boring near the north-east corner of the Bridgeness workings,† but in No. 6 Pit, Grange, it is 8 ft., while in No. 18 Pit, Kinneil (Lothians Pit), it is reported to be 59 ft., thus showing a rapid increase towards the west. It seems possible, however, that the thick band last mentioned may include two or more flows which come together without any sedimentary parting. In the Snab Pit the position of the Red Coal seems doubtful: if the 6-in. coal at a depth of 902 ft. represents it, then the overlying igneous rock, without any sedimentary parting, is in this locality as much as 91 ft. thick, which would show a still further increase in thickness in a westerly direction. But if Mr. Cadell is correct in regarding this 6-in. seam as the Wandering Coal, the bottom lava which lies above the Red Coal must have died out in a westerly direction between the No. 18 Pit and the Snab.

The vesicular bottom of the lava on the east side of Bonnytoun Hill is well exposed at the mouth of an old day-level nearly half a mile N.N.W. of Upper Bonnytoun. Part of it is not more than 5 in. above the top of the coal, but does not seem to have produced any appreciable alteration therein. It shows a "pillow structure," being divided into large rounded vesicular masses, 2 or 3 ft. in diameter, some of which are to a large extent, if not entirely, isolated from one another by partings of clay shale.

In a vertical face of the trap mass which comes above the Red Coal about 300 yds. S.S.W. of the seaward end of Bridgeness Pier, a parting of dark micaceous sandstone, about 5 in. thick, appears to include pieces of trap and to descend in places in thin strings into the underlying rock.

In a quarry a quarter of a mile north-west of North Bank three bands of basic igneous rock are seen, of which the lower, lying above the sediments which include the Wester Main Coal, is about 30 ft. thick. The middle band is 18 or 20 ft. thick, and the top of the upper is not exposed. Between the lower and the middle band there is in one place, but not generally, a parting of sediment, about a foot thick, and several round lumps of vesicular trap which appear in vertical section to be entirely surrounded by sediment.‡ The parting of sediment which separates the middle and the upper bands is only 2 or 3 in. thick. Specimens from both of these partings (11751 from the upper and 11752 from the lower) have been examined under the microscope by Dr. Flett, and are stated by him to show considerable alteration. The polished face of 11752 shows very well the irregularities of the igneous surface on which the sediment lies, and which frequently forms little projections, facing in one direction, which may possibly indicate overfolds in the original flowing surface of a lava. The higher layers of sediment

* It was in the western exposure that the remains of the lycopod stem, described by H. M. Cadell ("The Occurrence of Plant Remains in Olivine Basalt in the Bo'ness Coal-Field," *Trans. Edin. Geol. Soc.*, vol. vi. p. 191), were found.

† H. M. Cadell, "The Carboniferous Limestone Coal-Fields of West Lothian," *Trans. Inst. Min. Eng.*, vol. xxii. 1901, p. 383.

‡ Since this description was written the quarry has been extended, and a somewhat different section exposed.

in the little hollows of the trap sometimes overlap the lower, and abut against the sides of the hollows. A few pieces of igneous rock seem to be isolated in the sediment, but the top surface of the main mass of lava is, through all its irregularities, much finer than the interior, and can in this locality have suffered little or no denudation. It seems indeed possible that it was hot and perhaps still flowing at the time the sediment was laid down on it.

In another quarry, two-thirds of a mile N.N.E. of Gardeners Hall, two bands occur, which are probably in a somewhat higher stratigraphical position but still below the Upper Ironstone: in the upper band, which is very vesicular, we find various streaks of siliceous material, sometimes 4 or 5 in. thick, which cross the igneous rock at various angles, sometimes steeply. They are much more siliceous than any common type of sediment found in the district, and are described by Dr. Flett as cherts (11753, 11754, 11755, 11786). They show no radiolaria or other traces of organic remains, but include pieces of extremely decomposed basalt or dolerite. Specimen 11786 was found by Dr. Pollard to contain 91·83 per cent. of silica.

In a quarry (at Bell's Knowe) nearly a quarter of a mile S.S.E. of Bo'ness Railway Station two lava flows are seen in about the same stratigraphical position as the bands in the quarry last mentioned. The lower flow is 40 ft. thick and separated from the upper by a thin layer of sediment, averaging about a foot thick, composed of micaceous shale, indurated sandstone and an impure coal, which, Mr. Cadell states,* has been crumpled and at one place completely doubled up by the overlying flow. The decomposed top of the lava under the coal is traversed by various calcareous streaks, one of which (11787) appears to Dr. Flett to have been marmorised along a thin layer at the contact.

Many loose blocks on the waste heap of No. 3 Pit, Kinneil, show an impure sandy sediment wrapping round large pieces of vesicular trap, which have perhaps come from near the horizon of the Wandering Coal (see p. 132).

In the southern part of the area many bands of igneous rock have been found in positions below the Red Coal, and the sedimentary partings are subordinate to them. These, however, are not well exposed at the outcrop, and it is doubtful where they first come in. In the boring No. 2 Bonnytoun (Kinneil), which is near the old mine near Upper Bonnytoun, the journal records one band between the Six-foot Coal and the East Main and another between the East Main and the Smithy. Farther south-east the borings No. 2 and No. 1 Parkhead show an excess of whinstone for several hundred feet below the probable position of the Red Coal.

Near the Forth the volcanic rocks that underlie the Upper Ironstone are succeeded by a series of sediments, about 270 ft. in thickness. The next volcanic zone is not far beneath the Index Limestone where an olivine dolerite of Dalmeny type (11772) occurs, which is well exposed at Bo'ness Distillery, its thickness there being about 24 ft., and its top 10 ft. below the limestone. Mr. Cadell states that a thin bed of ash was formerly exposed just beneath the lava in this locality. Both westward and southward from the distillery this

* "Notes on the Volcanic Rocks of the Borrowstounness Coal-Field," *Trans. Edin. Geol. Soc.*, vol. iii. p. 311.

volcanic zone increases considerably in thickness, being 51 ft. in the Snab Pit No. 1, and about the same in No. 3 Pit, Kinneil.*

Farther south, near the Avon and the Little Mill, the section below the Index Limestone is very different and shows more igneous rock. Fifty yards above the foot of the burn that comes into the Avon from the north nearly a third of a mile north-west of the Mill, the coal below the Index rests directly on a fine-grained, reddish-brown mudstone, 18 or 20 ft. thick, which contains in places round lumps of dark igneous rock about a foot long. The top of the mudstone is penetrated by many narrow cylindrical harder parts, which perhaps represent fossil rootlets. Underneath it come 9 or 10 feet of shaly or flaggy sandstone underlain by tuff—the top of the Little Mill ash, which is so well exposed in the big scars on the river side between this locality and the Little Mill. It is generally of a dark-green colour, false-bedded and full of fragments of decomposed vesicular trap, often about half an inch long, together with other much larger and fresher pieces. The larger occasionally attain a length of several feet, are somewhat round and perhaps represent "bombs." Mr. Cadell states that the bed contains pseudomorphs of splinters of coniferous wood, in which the woody substance has generally been entirely replaced by calcareous matter.†

The dip is usually at gentle angles, rarely as much as 25°, and near the Little Burn it is in the same direction and of much the same amount as that of the overlying sediments. In the burn S.S.W. of Swordie Mains, however, the ash dips nearly south at gentle angles, though it is almost certain that the underlying sediments on the south-east side must have a westerly inclination. The appearances may be best accounted for on the supposition that the beds of ash were originally piled up so as to form a bank with the layers on either side inclined outwards at angles of 20° or 30°. A series of borings (Balderston borings) just on the north side of the scars of tuff in the Avon have pierced considerable thicknesses of sediment mixed with rock, recorded as "whin," presumably ash in these cases. Hence it is clear that the ash must be of very irregular distribution. Perhaps it lies very near a submarine volcanic neck (of earlier date than the Index Limestone) and from time to time the materials may have been irregularly sorted under water. The boring No. 6 Kinneil (see p. 136) begins in the tuff about 150 yds. east of the Mill, and goes down 490 ft. before meeting the first band of sediments, which consists of blaes and faky fireclay about seven feet thick. Mr. Cadell supposes this boring has pierced the volcanic neck which supplied the ash,‡ but the bedding in the tuff only 30 yds. away is almost horizontal, and at various depths below the sediments described other thin bands of blaes are recorded, down to the bottom at 691 ft.

In the burn a third of a mile north-west of the Mill a band of decomposed dolerite (11771) occurs a little above the top of the tuff. This must be nearly on the same stratigraphical position as the trap at Bo'ness Distillery, but possibly it is of intrusive character.

About 230 yds. N.N.E. of the Snab Pits a band of olivine dolerite (11773), probably a lava flow, is exposed at the roadside and was

* H. M. Cadell, *op. cit.*, plate facing p. 312. † *Op. cit.*, p. 313. ‡ *Op. cit.*, p. 318.

formerly visible on the foreshore a little farther north-west. The stratigraphical position seems about 150 ft. above the Index Limestone, for Snab Pit No. 1 pierced a band of "whinstone," 5 ft. 6 in. thick, in this position, very near the top of the shaft. In the Avon near the Avon Mills east of Waukmilton, and in the water-course north of the mill, a band of much decomposed porphyritic olivine basalt (11774) occurs, and in boring No. 1 Langloan, about 200 yds. west of Kinneil Mills, this band was again found, with a thickness of 22 ft., and its base about 90 ft. above the Index Limestone. As the sedimentary beds above this limestone seem to become thicker northwards to the Forth (see p. 141), it is possible that the band is the same as that exposed near the Snab Pits, especially as it appears to have been met in several bores a little north of the Avon, including No. 2 Russell, in which the base was 110 ft. above the Index Limestone.

About 300 yds. west of the Snab Pits a slightly higher band of "greenstone" was also formerly exposed on the foreshore, but is now deeply covered under artificially made ground.

The top of an ash bed is obscurely seen in a little burn about 170 yds. N.N.E. of Kinneil Mills: its stratigraphical position is possibly 40 or 50 ft. below the Kinneil Mills Limestone; the thickness is perhaps only a few feet.

About 11 ft. below the outcrop of the Kinneil Mills Limestone in the Avon a thin oolitic, calcareous, ferruginous bed contains green chloritic patches (11746), which Dr. Flett supposes may possibly represent pieces of decomposed ash.

In a still higher position, perhaps nearly half-way between the Arden (Dykeneuk) and Castlecary (Leven Seat) Limestones, we find two other thin oolitic, calcareous, and ferruginous beds, the lower of which (11748) contains lumps stated by Dr. Flett to have some resemblance to volcanic spongy lapilli. C. T. C.

In the neighbourhood of Charlestown on the north side of the Forth, the volcanic group of the Bathgate Hills is represented only by some thin beds of tuff interstratified with the Lower Limestone group. A bed of coarse tuff overlies a limestone in the railway cutting three-quarters of a mile west of Charlestown Station, and several beds of green tuff are interstratified with sandstone in the middle of Ironmill Bay. A broad exposure of greenish tuff, near low-water mark in the middle of the Bay, may mark the site of an ash-neck, the sedimentary rocks close to the tuff being tilted up at high angles. H. B. M.

Volcanic Necks West of Edinburgh and the Pentland Hills.

In the upper Oil-shale group and basal beds of the Carboniferous Limestone series masses of agglomerate and tuff occur, sometimes pierced by irregular intrusions of basalt. In some cases these necks form prominent features in the landscape; in others they are known only through underground mining operations. Very interesting in this respect is the neck at Gallowscrook, near Philpstoun, described below.

Beyond the fact that the necks must be later than the sediments

through which they cut, there is no direct evidence as to their age, but it will be noticed from the map that these necks all lie to the eastward of the lavas and tuffs of the Bathgate Hills, and pierce rocks, which lie below or at the base of the extrusive rocks. There can therefore be little doubt that the necks mark some of the orifices through which the Bathgate Hills volcanic series were erupted. The petrographical similarity of the tuffs and basalts occupying the necks with the bedded tuffs and lavas further strengthens this view. H. B. M.

The ground plan of the neck at Niddry Castle forms an irregular oval, the longest axis measuring 500 yds. It is filled with a fine-grained, dull green tuff which in places contains small fragments of black shale and grains of carbonate of copper. The ash is unstratified and in places contains large fragments of shale and ironstone. Two intrusions of dolerite intersect the western side of the neck, and on its north and south sides the surrounding strata roll over and are inclined towards the vent.

The Tar Hill vent lies directly north of Ecclesmachan village, and forms a conspicuous feature in the landscape with the deep hollow of the Niddry Burn encircling its southern and western sides, while the eastern flank is a long sloping drum of boulder clay. Its longer axis measures 700 yds. The rock is a fine-grained, unstratified tuff with many baked fragments of shale.

Two small orifices occur at West Broadlaw and south of West Binny, which are filled with dull yellowish and green tuff with small indurated fragments of shale and sandstone.

The neck at Gallowscrook half a mile east of Philpstoun does not appear at the surface, but was found during mining operations in the Broxburn Seam at this locality. A mine, 360 ft. in length, crossed the vent, and the walls were found to be quite perpendicular but somewhat slickensided, doubtless due to the subsidence of the materials. The oil-shale was unaltered to within a foot or two of the ash, and in common with most necks the strata for some little distance dip towards the vent. The tuff varies in character and structure, is chiefly fine-grained with occasional large blocks of black shale or, again, it contained small veins of pitch or solid paraffin.*

If the extent of ground covered by tuff round any one neck forms any criterion as to the actual size of the vent, that of Binns Hill would then be the largest in this district. It is quite possible, however, that the actual neck is smaller than the area shown on the map and that a portion of the ash-covered ground includes material heaped up outside the margin of the vent.

One small exposure of tuff in a quarry and another in a small cliff below probably indicate the presence of a small neck at West Shore Wood. The green agglomerate contains rounded and angular bombs up to one foot in diameter. Blocks of dark greenish grey tuff probably mark the position of a small neck on the shore a short distance to the east of Society. J. S. G. W.

A small volcanic neck, filled with coarse agglomerate, is exposed in the Brox Burn below the filter beds for the Bangour Asylum Reservoir. The agglomerate, in contrast with the bedded tuff

* H. M. Cadell, *Trans. Inst. Min. Eng.*, 1901, vol. xxii. p. 353.

exposed higher up the burn, contains abundant large blocks of agglomerate and of sedimentary rocks. It truncates the edges of the surrounding shales and sandstones, which are greatly disturbed.

The conical hill of tuff that forms the summit of the Riccarton Hills may be a neck, but the relations with the surrounding basalts are obscure. H. B. M.

In the Calciferous Sandstone and basal beds of the Carboniferous Limestone series, in the neighbourhood of Linlithgow, masses of coarse agglomerate occur, sometimes forming prominent features, as at Pilgrims Hill north of the Poorhouse, east of Cauldhame and east of Parkly Place. The lapilli are sometimes an inch across, but usually smaller. They are composed chiefly of igneous material, but carbonised plant fragments are common. The microscope shows that sand grains form a considerable part of the finer material between the larger fragments. Basalt intrusions, in the form of plugs or thin dykes, are frequently connected with these masses of ash, and are composed of rock similar in appearance to that of the lavas, but a specimen from one of the plugs 700 yds. north of Riccarton was found on microscopic examination by Dr. Flett to contain analcime.

The adventitious appearance of the masses of ash referred to, their oval or circular plan, their massive character, unbedded appearance, and their intimate association with intrusive rocks similar to the lavas, support the conclusion that these masses represent filled-up vents whence the lavas in the overlying strata have been poured out. G. W. G.

CHAPTER X.

CALCIFEROUS SANDSTONE SERIES OF THE MID-LOTHIAN BASIN.

The Mid-Lothian Coal-field lies, as already stated, on the eastern side of a line of powerful disturbance—the Pentland fault—trending N.N.E., which has brought up the older Palæozoic Rocks of the Pentland Hills on the west (see horizontal section in Sheet 32, colour printed edition).

Within this coal-field an important development of true Coal Measures forms a basin, the axis of which is nearly parallel to the fault. It seems probable that the synclinal arrangement of the strata has been developed under the influence of considerable earth pressure acting from a westerly direction, for on the west side of the basin the rocks often dip at high angles, from 50° to 90°, or are even reversed, while on the east the inclination does not usually exceed 25° or 30°.

The strata are divisible into various groups, the positions and general thicknesses of which are shown in the following table :—

Upper Carboniferous.		Middle Coal Measures (?), perhaps 460 ft. Lower Coal Measures, perhaps 1300 ft. Millstone Grit or Roslin Sandstone Series, upper portion, often about 400 ft.
Lower Carboniferous.		Millstone Grit or Roslin Sandstone Series, lower portion, often about 200 ft.
	Carb. Limestone Series.	Upper Limestone Group, from 550 to 1070 ft. Edge Coal Group, from 550 to 1000 ft. Lower Limestone Group, from 240 to 540 ft.
	Calciferous Sandstone Series.	Oil-Shale Group, more than 2000 ft. at Straiton, but probably diminishes greatly southwards and eastwards. Cementstone Group.

The detailed examination of the Mid-Lothian basin has proved that in the north-west portion of the area, in the neighbourhood of Niddrie, the strata are unusually thick, while both in a south-western and an eastern direction from that locality all the groups diminish in thickness, and the coals of the Edge Coal series become fewer and thinner.* The only exceptions are some of the limestones. Between Niddrie and the Emily Pit, Arniston—a distance of about six and a half miles in a S.S.E. direction—the Edge Coal group thins down from about 1050 ft. to about 600 ft., and there is a strong presumption that the diminution continues still farther in a southerly direction from the Emily Pit. At Mauricewood, near Penicuik, the decrease is also marked, the thickness of strata between the top of the highest and the bottom of the lowest coal in this division being only slightly more than 500 ft. (see p. 211). At

* Most of these points have been illustrated in the vertical sections engraved on the margin of the colour printed edition of the one-inch map 32.

the same place the total thickness of the coal seams in the group referred to is diminished to 44 ft., while at Loanhead—hardly four miles away—it is 97 ft. In the Lower Limestone division the diminution in thickness from Gilmerton to Middleton and Esperston is equally pronounced, from about 700 ft. to about 200 ft.

It will also be seen from the vertical sections in Sheet 32 that the Lower Coal Measures and the Edge Coal group include a valuable series of coals, and are separated from each other by a somewhat barren division composed of the Roslin Sandstone series (Millstone Grit) and the Upper Limestone group. Some coals of good quality are found in certain districts among both the Upper and the Lower Limestones, and thin impure limestones and marine horizons are known to occur in the Coal Measures, and also in the Roslin Sandstone series and Edge Coal group. It is noticeable in this district, as in many others, that the limestones and marine horizons often lie only a little distance above coals and fireclays.

The length of the basin formed by the true Coal Measures, from the sea at Musselburgh to the southern extremity beyond Rosewell, is rather more than nine miles. Its breadth varies considerably from place to place, chiefly in consequence of cross faults, but it probably never exceeds three and a half miles.

Round the central basin of Coal Measures the Roslin Sandstone series forms a belt which is particularly narrow in the north-west area in consequence of the unusually steep inclination of the strata. It also extends for a considerable distance in a south-westerly direction past Penicuik to Auchencorth Moss, near the southern margin of the map.

Outside the rim formed by the Roslin Sandstone the different divisions of the Carboniferous Limestone series are affected by various folds. Thus on the west, near Gilmerton, a compound syncline causes the outcrop of the Carboniferous Limestone series to extend locally nearly three-quarters of a mile west of its usual line of crop. A little farther south near Broomhills and Bilston Burn, the Gilmerton syncline may still be recognised lying to the west of the Straiton anticline (see Fig. 13, p. 163). It will be observed that at the west side of this section the beds are reversed near the Pentland fault, as is often the case in other places situated along this belt of disturbance. On the east side of the basin there is one important anticlinal fold with a N.N.E. axis, along the centre of which beds belonging to the Lower Limestone group emerge at Cousland and the Roman Camp. On the eastern side of this anticline the Edge Coals dip E.S.E. and extend eastwards into the East Lothian Coal-field (see "The Geology of East Lothian," 1910, *Geol. Sur. Mem.*).

The strata on the south-western side of the Musselburgh and Rosewell basin of Coal Measures are affected by various folds, some of which appear to die out before they reach the basin, and along the synclinal portions of these folds we find various small outliers of Coal Measures, one just south of Penicuik and another a mile and a half S.S.W. of that town.

In this district the Calciferous Sandstone series is chiefly confined to the western side of the basin, but it occurs also to the south-east of the Lower Limestone group near Borthwick and

Old Middleton. As will be noticed subsequently, it includes some beds of marine limestone of much the same type as those in the Carboniferous Limestone series.

The boundary line between the Calciferous Sandstone and the Carboniferous Limestone series has been drawn at the base of the Gilmerton Limestone, which, in the Bilston Burn, has been converted into ochre. But a considerable amount of stratigraphical and palæontological evidence has been accumulated, partly by Mr. Macconochie, which makes it not improbable that a lower limestone, the base of which in the Burdiehouse Burn lies 130 ft. below the Gilmerton Limestone, really corresponds to the Lower Longcraig Limestone of Dunbar, which, in that locality, is taken as the base of the Carboniferous Limestone series. The little limestone referred to rests directly on a calcareous shale with abundant remains of *Rhipidomella* [*Orthis*], underlain by a thin pyritous shale, a few inches thick, with fish remains and *Lingula*. A shale with *Schizophoria* and *Rhipidomella* and a similar fish bed occur below the Lower Abden Limestone on the coast of Fife, which in all probability corresponds in position with the Lower Longcraig of Dunbar, though neither the shale nor the fish bed has there been found in connection with it.

The chief dislocations affecting the coal-field strike approximately east and west, and have a downthrow to the north, as, for example, the Sheriffhall fault—which passes through Dalkeith—and the westerly continuation of the large north-east fault at Vogrie. The displacements effected by both these faults appear to be very large near the centre of the basin, but much less at the sides, and this fact has led to the supposition that they were developed in great part simultaneously with the folding that produced the synclinal arrangement of the strata.

One of the best sections in the district is that on the shore at Joppa, which extends from about the middle of the Upper Limestone group, through the Roslin Sandstone series, into the Lower Coal Measures. It has been measured by W. Gibson and D. Tait, and the details are shown in the horizontal section (Plate VII.), but it should be stated that the coal seams are not well seen, and the positions of some of them are doubtful.

Probably the best inland section of the Carboniferous strata is that in the Bilston Burn, on the west side of the basin, near Loanhead, which cuts the lower part of the Roslin Sandstone series, the whole of the Carboniferous Limestone and part of the Calciferous Sandstone (see Fig. 15, p. 181). The lower beds of the true Coal Measures are well exposed in the North Esk near Elginhaugh, in the South Esk near Newbattle Abbey and in the railway cutting near Broomieknowe Station. C. T. C.

Oil-Shale Group.

Portobello, Niddrie, and Gilmerton Area.

Certain oil-shales to the west of Niddrie have been artificially exposed, but they have never been wrought, and the record of the precise position of their outcrops has been lost. We have no exact

knowledge of even the upper portion of the Calciferous Sandstone group north of Gilmerton, but near this village the Burdiehouse Burn twice in its course affords a good section of strata underlying the Gilmerton Limestone. At Hyvots Bank, just above the first crossing of the limestone by the stream, the section is more extensive, though not so clear as that exposed farther down stream, for a short distance above the bridge of the main road. The Hyvots Bank section has, moreover, the advantage of showing the beds in question passing naturally beneath the Gilmerton Limestone, while in the other section a small fault obscures the relationship. The two sections agree in their details, which are shown below, in descending order, as far as the down-stream section extends.

	Ft.	In.
GILMERTON LIMESTONE, Black Shale (middle portion burns) ..	10	0
LIMESTONE, almost entirely consisting of remains of *Productus semireticulatus* and *P. longispinus*	2	0
COAL of poor quality	2	0
Fireclay	5	0
Sandstone	9	0
Dark Fireclay	8	0
Ironstone band with plants and fish remains	1	0
Dark Shale*	6	0
Coal daugh	2	0
Flaggy Sandstone	25	0
Sandy Shale	12	0
Black Carbonaceous Shale	6	0
LIMESTONE, dark	0	10
Black Shale	13	0
Black Shale	3	0

The Hyvots Bank section shows some still lower beds, namely—

	Ft.	In.
LIMESTONE, dark	1	0
Dark calcareous Shales with LIMESTONE nodules	10	0
LIMESTONE, dark shaly	10	0
LIMESTONE, massive grey encrinital, with *Rhipidomella* band at base	3	0
Thin band with *Lingula* and fish bones ("bone bed") ..	0	2
Dark Shale	4	0
Grey Shale with ironstone nodules	6	0
COAL, Parrot	0	6
Grey Shale (passing down into faky sandstones) at least ..	7	0

Where the grey shale at the bottom of the above section is reached in the burn, a fault reintroduces the lower part of the limestone and the bone bed.† The Parrot Coal in this second exposure is overlain by a 2-in. blackband ironstone with remains of entomostraca. The sandstones beneath the grey shales are not well seen; they are thin, however, and in the second exposure are underlain by grey marls with calcareous concretions.

Below these marls there is a gap in the section, but from comparison with the fuller sequence of the Bilston Burn section, to be described in the sequel, it is probable that these grey marls rest upon

* In this section "Shale" does not imply oil-shale as in the Diamond Bore Section on p. 164.

† This bone bed, both here and in Bilston Burn, was first discovered by Mr. Macconochie.

a considerable mass of grey faky sandstone, part of which is cut out by the continuation of the fault which, as already mentioned, reduplicates a portion of the section farther down stream. Be this as it may, the next beds below the faky sandstones of Bilston Burn are exposed in the Burdiehouse Burn a little below the Lasswade road, and consist of a mass of grey sandy shales overlying a thin grey shaly marine limestone—the Cephalopod Limestone of Bilston Burn. It should be mentioned that a coal, reputed to be about two feet thick, was wrought in Bilston Burn at a slightly higher horizon than these grey shales, and although not actually exposed in Burdiehouse Burn it would probably be easy to locate the outcrop.

It is interesting to recall that Mr. John Henderson was the first to draw attention to the occurrence of marine limestones below the Gilmerton Limestone in this burn section.* The relations of these marine bands to the Lower Abden Limestone in Fife will be referred to in the sequel (p. 170). E. B. B.

AREA BETWEEN STRAITON AND GLENCORSE BURN.

No representatives of the Cementstone group have been detected in this area, but the tract is one of economic importance from the presence of a succession of valuable oil-shales overlying the Burdie-

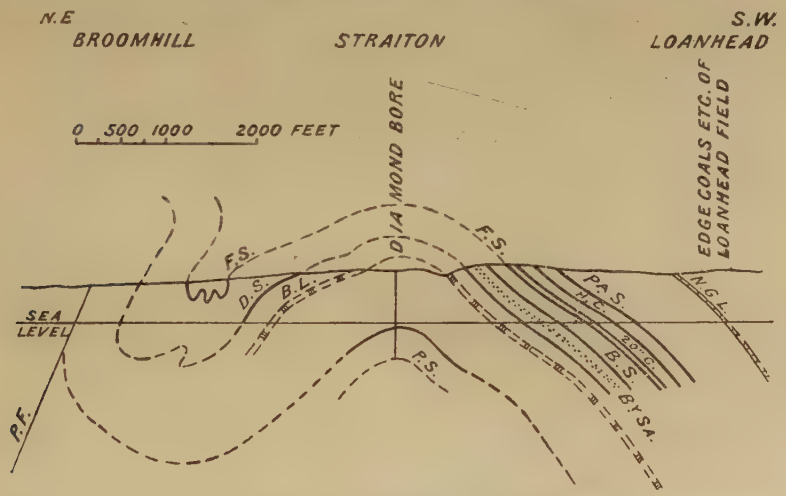

FIG. 13.—Section of Burdiehouse and Straiton Shale-field.

P.S. Pumpherston Shale. B.L. Burdiehouse Limestone. D.S. Dunnet Shale. By.Sa. Binny Sandstone. B.S. Broxburn Shale. F.S. Fell Shale. H.C. Houston Coal. PA.S. Paper Shale. N.G.L. North Greens Limestone. P.F. Pentland Fault.

house Limestone at Straiton, which represent some of the well-known seams in West Lothian. Much information regarding the succession of the oil-bearing strata is available from mining records, which can be supplemented as regards the higher portion of the Oil-shale group by the excellent natural section of Bilston Burn.

The main structural features may thus be briefly summarised.

* "On some Marine Beds underlying the Gilmerton Limestone," *Trans. Edin. Geol. Soc.*, 1882, vol. iv. p. 217.

A well-marked anticlinal fold runs in a N.N.E. direction near Straiton, on whose western side the beds form a compound syncline, the western limb being inverted next the Pentland fault. The latter fold is a continuation southwards of the Gilmerton trough. On the eastern side the members of the Oil-shale group plunge beneath the Carboniferous Limestone series at high angles. In the southern portion of the mined area, near Pentland Mains, the three seams are thrown into a sharp compound anticline, and after passing over this flexure the different outcrops, without any break, resume their former trend.

The most important geological horizon in this area is the Burdiehouse Limestone which has been wrought only on the east side of the Straiton arch, but its position to the west has been proved in bores. To the north its outcrop is truncated by a fault with a downthrow of 60 fms. in that direction, which crosses the Straiton anticline with an east and west trend and is probably the continuation of the Sheriffhall dislocation.

Definite information concerning the nature of the strata below the Burdiehouse Limestone is afforded by a diamond bore at Straiton which was put down in the centre of the anticline (Fig. 13). It begins a short distance below the limestone and its general features are given in the following section :—

Diamond Bore, Straiton (condensed).

		Ft.	In.
	Surface	69	6
	Blaes	38	0
	LIMESTONE (fossils)	1	9
	Fakes and Blaes	9	5
	Sandstone	4	6
	Fakes and Blaes	49	5
	Sandstone, brown	45	4
	Fakes and Blaes	70	2
	Shaly Blaes	1	0
	Blaes and Fakes	14	1
	Sandstone, limy posts	14	7
	LIMESTONE (fossils)	1	0
	Blaes and ribs	11	2
	COAL	0	1
	Fakes and Fireclay on top	25	11
	Sandstone	31	7
	Blaes, Fakes and ribs	35	0
	LIMESTONE (fossils)	0	8
	Faky Blaes and ribs	37	0
Oil-Shales at Pumpherston position.	Shale	0	4
	Limy Fakes and Blaes	64	0
	Shaly Blaes with rib	5	0
	Sandstone and Blaes	7	2
	Shaly Blaes	11	5
	Blaes with cement ribs	30	10
	Sandstone with partings	8	11
	Blaes with cement ribs	32	4
	Sandstone with partings	43	5
	Blaes	51	8
	Marls, Blaes with cement ribs	27	10
	Faky Blaes and ribs	87	1
		830	2

The shale and shaly blaes lying between 460 and 548 ft. from the top apparently represent the Pumpherston position.

To the east of Crawley Cottages in Glencorse Burn, a 4-in. coal and thin limestone band with blaes are seen in the bed of the stream. A gap equivalent to 100 ft. of strata here occurs, beyond which comes a thick brown sandstone dipping again to the east. This thin coal may possibly be the equivalent of the 1-in. seam in the Straiton bore, and the sandstone may represent the brown sandstone, 45 ft. thick, which lies 112 ft. above this coal.

Higher up the stream the following section is exposed :—

	Ft.
Black blaes with cement bands	8
Grey blaes and fireclay	10
Sandstone, banded	4

Burdiehouse Limestone.—Reference has already been made in Chapter VI. (p. 47) to Dr. Hibbert's classic paper on the limestone at Burdiehouse, in which he called attention to the absence of true marine organisms and advocated its fresh-water origin from the occurrence in it of plants, entomostraca and fish remains chiefly of Palæoniscid fishes.

After a prolonged study of Scottish Carboniferous ichthyology, Dr. Traquair has been led to the conclusion that the distinctive fish fauna of the Burdiehouse Limestone implies estuarine as opposed to marine or open sea conditions. The fish remains are frequently found, though not in the Burdiehouse Limestone itself, in association with *Lingula* but not with the hinged brachiopods, such as *Productus.*

In the previous edition of this memoir, Salter remarked * that "the fossils found in the Burdiehouse Limestones are for the greater part distinct from those of other parts of the Lower Carboniferous series. This may be partly due to greater attention having been paid to this celebrated limestone by collectors." In commenting upon this sagacious inference Dr. Traquair notes that "this explanation of a supposed fact has indeed proved to be true even in a more emphatic sense than is implied by the word 'partly.' As regards the fishes, at least, if we leave out of consideration the names cancelled above, all the species contained in the Burdiehouse list, except *Megalichthys laticeps* and *Uronemus lobatus,* occur in the Dunnet Shale above and many of them in the Wardie Shales below." †

The following is a vertical section of the Burdiehouse strata quoted from Hibbert's description :‡—

a. Argillaceous and bituminous shale of a very dark colour, alternating with which are thin seams of ironstone, and three or more very thin seams of limestone, the latter being from 2 to 2¼ in. thick, and at intervals from each other of 27 to 36 in. From 30 to 50 ft. of shale are exposed.

b. The limestone of Burdiehouse, 27 ft. thick.

c A pavement of rather soft blaes, 2 or 3 ft. thick. This is an argillaceous and bituminous shale mixed with calcareous matter, and forming, near the junction of the rock, or immediately subjacent to it, an impure limestone.

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* "The Geology of the Neighbourhood of Edinburgh," 1861, p. 146.

† *Trans. Roy. Soc. Edin.*, 1903, vol. xl. p. 692.

‡ *Trans. Roy. Soc. Edin.*, 1833–4, vol. xiii. p. 244.

d. Limestone of inferior quality, 3 or 4 ft. thick.
e. Black blaes (argillaceous and bituminous shale), rather soft, 3 or 4 ft. thick.
f. A seam of coal, 6 to 10 in. thick.
g. "Yellow clay" (an argillaceous and shaly sandstone ?). Some of the workmen describe this bed as metal, and as forming a very coarse freestone. Depth unknown.

The beds of argillaceous shale, both above and below the limestone, contain the same organic remains as the latter.

The limestone is regularly stratified and of various tints, often bluish grey or blackish grey from the bituminous or vegetable matter which is so abundantly diffused through it. It possesses a dull and earthy fracture, the rock being charged with innumerable tests of ostracods. It breaks very readily along the bedding planes where the bands of limestone alternate with thin laminæ of vegetable or bituminous matter. Where these are absent it breaks with a conchoidal fracture.

For over one hundred years the limestone has been opened out by a series of quarries between Straiton and Burdiehouse Mains. To the south-west of Straiton its position has been proved by numerous bores, and to the south of Pentland Mains there are traces of several old quarries. From this point to the west of Penicuik it cannot be traced, but it is possible that it extends to the south of the Glencorse Burn, for below Crawley Cottage cementstone bands are exposed in this stream. This bed is at present only wrought at two localities: at the Straiton Oil Works by a pit sunk 50 fms. with stoop and room workings, and at the opencast quarry to the east of Burdiehouse Mains by a mine 160 fms. in length.

The workings along the north face of this mine have proved the position of an east and west fault with 60 fms. downthrow to the north, to which reference has already been made. The average dip in the quarries is 20° to 30°, and in the underground workings 47° to the south-east.

To the south-east of the quarried outcrop of the Burdiehouse Limestone between Pentland and Burdiehouse Mains is situated the oil-shale field recently wrought by the Clippens Oil Company. The proved ground is two miles in length with an average breadth of 600 yds. and contains several workable seams.

The oil-shales above the limestone are shown in the following section:—

	Ft.	In.
Paper Shale		
Strata to	133	0
Houston Coal		
Strata to	51	8
Twenty-inch Coal		
Strata to	46	8
Fells Shale		
Strata to	145	1
Broxburn Shale		
Strata to	264	11
Dunnet Shale		
Strata to	177	0
Burdiehouse Limestone.		

The actual outcrops of the Dunnet, Fells and Broxburn Shales have been proved by mining and the remaining coals and shales by

bores and trial pits. A glance at the map will show how closely these different seams follow the outcrop of the limestone. To the south of Pentland Mains the two lowest shales are thrown into four successive folds, but apart from these flexures the structure of the field is very simple. It is crossed by no faults of any importance and the different beds dip to the south-east beginning at 44° and increasing to 58°.

The Dunnet Shale is from 5½ to 6 ft. thick, yields from 25 to 26 gallons of oil and 20 to 23 lb. of sulphate of ammonia per ton of shale, and is rich in solid paraffin, known technically as "scale." The roof of this seam is composed of soft friable blaes which is a disadvantage in mining the shale.

The roof and floor of this bed have yielded a rich fish fauna to Dr. Traquair.* He remarks that "of the twenty-one accurately determined species here recorded, twelve occur in the Burdiehouse Limestone below, which was considered to be a 'fresh-water limestone' by Dr. Hibbert. Fragments of cephalopodous shells in the roof-shale bear witness to the fact that marine conditions were not far off, and that 'estuarine' is rather a better word in the circumstances."

The Broxburn Shale gives from 20 to 22 gallons of crude oil and 20 to 21 lb. of sulphate of ammonia per ton. It has a strong roof and is more cheaply wrought than the Dunnet Shale. It shows the following section:—

	Ft.	In.
Blaes	2	0
Ironstone Band	0	6
Blaes	3	4
Shale	3	3
Irony rib	0	1
Blaes	1	5

The Fells Shale, on account of its thinness and hardness, would not be a workable seam were it not for its extreme richness, yielding 34 to 35 gallons of crude oil and 10 to 19 lb. of sulphate of ammonia per ton.

The Twenty-inch and Houston Coals are both thin and dirty, and have never been worked in this field.

The Paper Shale has been opened out at its outcrop and is a thin, finely laminated shale. It has never been wrought and may be the equivalent of the Raeburn or Mungle Shale of West Lothian.

The section in the Pentland cross-cut mine is given in the subjoined table, and the Broxburn section is placed alongside for comparison.

In the Pentland section the Binny Sandstone is 65 ft. thick and at Broxburn 277 ft. In the eastern field three limestones with a total thickness of 41 ft. lie above the Binny Sandstone, which are not found in the Broxburn field. The Broxburn marls are not represented in the Pentland section.

* *Trans. Roy. Soc. Edin.*, 1903, vol. xl. p. 692.

Comparative Table of Strata in Pentland Cross-Cut Mine and at Broxburn.

Pentland Cross-Cut Mine.	Ft.	In.	*Broxburn.*	Ft.	In.
SHALE, FELLS	1	8	SHALE, FELLS	3	0
Fakes	8	10	Blaes	5	0
Ironstone with thin bands and Blaes	24	0	LIMESTONE	4	0
Sandstone	13	6			
Blaes	3	7			
Rock	4	0			
Blaes	1	6			
Sandstone	9	3	Hard Marls	248	0
Blaes	3	11	SHALE	1	1
Sandstone	9	0	Blaes and ribs	12	3
„ and Blaes	18	0	SHALE	0	8
„ hard	16	0	LIMESTONE	0	6
Blaes	23	6	SHALE	1	6
LIMESTONE, dark	0	4	Blaes	3	10
Blaes	2	3	SHALE, grey	5	10
SHALE, brown	0	2	Blaes	5	4
Blaes	3	0	SHALE, curly	5	6
SHALE, poor	0	9	Blaes	4	0
SHALE, BROXBURN	3	6	SHALE, BROXBURN	5	0
Blaes	11	6	Blaes	19	0
SHALE	1	8			
Daugh	0	3			
LIMESTONE	7	6			
Blaes	10	6	Marly Fakes	69	0
LIMESTONE	16	0			
Fireclay	23	8	Blaes and shaly Blaes	29	2
LIMESTONE, hard	17	0			
Fireclay	0	8			
Sandstone	0	6			
Daugh	5	10			
Sandstone	2	1			
Blaes	13	0			
Sandstone	65	0	Binny Sandstone	277	4
Blaes	60	0			
Ironstone	0	1			
SHALE	2	2	Sandstone and faky Blaes	46	10
Blaes	14	6	Faky Blaes	25	3
Daugh	6	0	SHALE	0	3
Blaes	0	6	Blaes	11	5
SHALE, DUNNET	6	6	SHALE, DUNNET	4	10
Blaes	3	0	Blaes	9	6
LIMESTONE	8	0	Limy Sandstone	34	6
Fakes	17	0	Blaes	127	6
Faky Sandstone	16	0	Sandstone and Blaes	133	10
Hard faky Sandstone	20	3	LIMESTONE	1	1
Fakes	1	6	Blaes	66	8
Faky Sandstone	21	0	SHALE, BARRACKS	0	6
Kennel	0	9	Blaes	12	5
Blaes	57	0	LIMESTONE	11	2
LIMESTONE, Burdiehouse	32	6	Sandstone } Burdie-	30	0
			LIMESTONE } house	0	4
	588	8		1216	1

The position of the Burdiehouse Limestone, as shown on the map on the west side of the Straiton anticline, is inferred from bores.

The Dunnet and Fells Shales have been got in the basin to the west, and the latter seam at Broomhills Farm appears in an inverted synclinal fold. The exposures are disconnected.

East of Broomhills Farm the beds in the Burdiehouse Burn dip to the south-east at very high angles and are sometimes vertical. They consist of black blaes with a bed of oil-shale. At the edge of the burn below the farmhouse a mine has been driven for a short distance into the shale, which is reported by Mr. Gemmell to be the Fells and about 2 ft. 6 in. thick. This seam occupies a small compound synclinal trough with steep sides. The shale was tested but found to be unsatisfactory. Between Broomhills and the Pentland fault a 4-ft. curly shale has been uncovered which was believed to be the Dunnet Seam. On the east side of the compound synclinal fold, and at the edge of the flat ground below Broomhill Cottage, this same shale was opened out by a pit. It dipped to north-west, was 4 ft. 7 in. thick and proved to be the Dunnet Shale lying about 130 ft. above the Burdiehouse Limestone.

Oil-shale crops have been opened out at various places between the Kames and Hyvots Bank, and at St. Catherines Well crude paraffin is found floating on the surface of the water.

Some years ago the South House property was bored, but the results were not satisfactory, although they were not such as to preclude the possibility of finding a valuable field to the north of the Burdiehouse fault.

Above the Paper Shale of Straiton there is no section to indicate the nature of the strata for 561 ft. of vertical thickness.

The section in the Bilston Burn commences on the east side of the Edinburgh road with a cream-coloured encrinital limestone. Eighteen feet above this horizon is a bed of blaes with oil-shale bands, which is overlaid by a grey encrinital limestone, 1 ft. thick. Next in order comes a calmy calcareous mudstone, 4 ft. thick, which has been termed the Cephalopod Limestone. Various strata, aggregating 73 ft. in thickness, separate this characteristic horizon from a coal reported to be 2 ft. thick, the latter seam being overlaid by 72½ ft. of beds, on top of which comes a very peculiar light-coloured lumpy fireclay with nodular concretions. Reference has already been made to the occurrence of the Cephalopod Limestone and the lumpy marl or fireclay in the Burdiehouse Burn section, near Gilmerton, which together with the *Rhipidomella* [*Orthis*] shale and fish band enabled Mr. Macconochie to institute a comparison of the sequence of strata below the Gilmerton Limestone in the two sections (Fig. 14).

The close correspondence in the sequence of zones in these two sections seems to involve the acceptance of an ochre bed (21 ft. thick) as the decomposed * representative of the Gilmerton Limestone (60 ft. thick). This correlation had been already reached on account of the close lithological resemblance of the sandstones above the ochre bed and limestone respectively, and also because both lie about 100 ft. beneath the North Greens Coal.

Another important point is the correlation of these Mid-Lothian sections with that on the Fife coast near Kinghorn, which Mr.

* Cf. C. T. Clough, "On the Disappearance of Limestones in High Teesdale," *Geol. Mag.*, 1903, p. 259; and C. A. Matley, *Q.J.G.S.*, 1906, vol. lxii. pp. 291, 293.

Macconochie's discovery of the fish bone bed has rendered possible. From general stratigraphical relations it will be readily conceded that the thin limestone beneath the Gilmerton (and ochre bed) might represent the first or lower Abden Limestone of Fife, so that when it is found to be underlain by a shale with *Rhipidomella* and

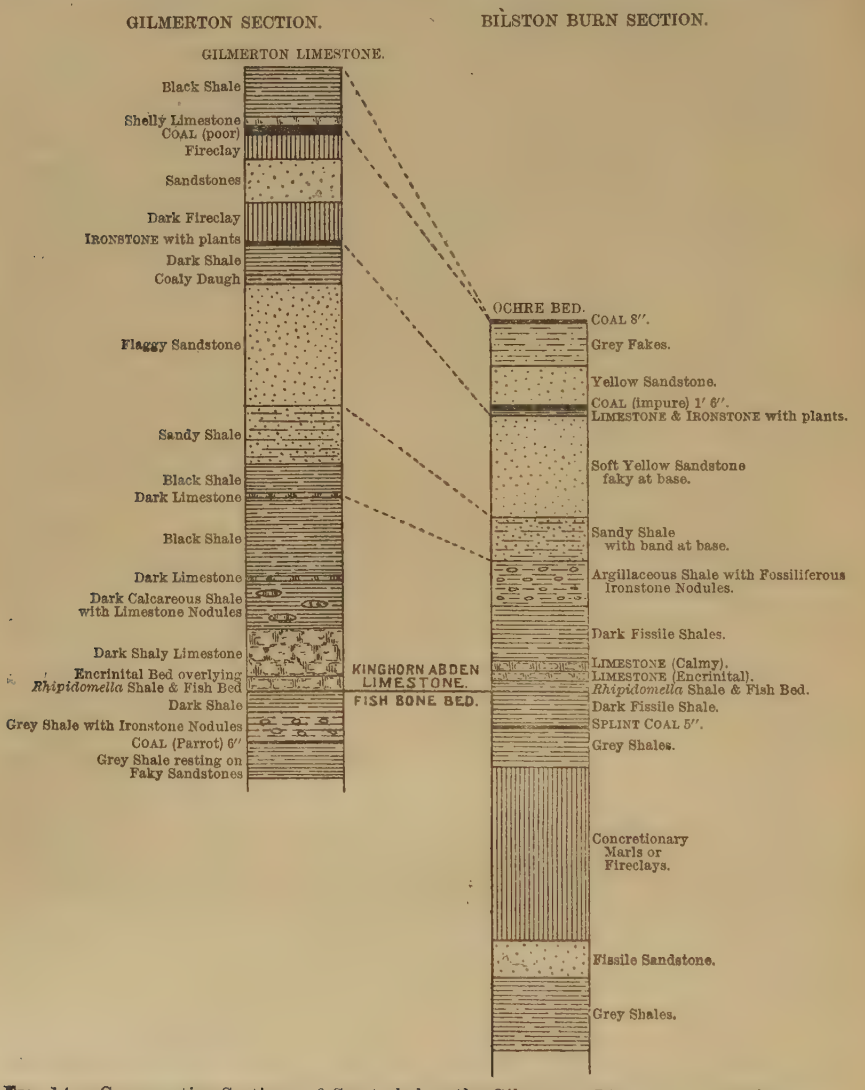

FIG. 14.—Comparative Sections of Strata below the Gilmerton Limestone in Burdiehouse Burn and in the Bilston Burn (scale 40 feet = 1 inch).

this in turn by a bed charged with fragments of *Lingula* and fish remains, just as in the Fife section, the grounds for correlation seem reasonably conclusive. It may be noted, however, that Dr. Traquair, who has determined the fish remains present, regards the bone bed by itself as inconclusive, for much the same assemblage of forms might be expected in any bone bed about this horizon. But the

crucial evidence that helps to fix the horizon is the stratigraphical relation of the bone bed containing *Lingula* to the shale with *Rhipidomella* and the limestone. J. S. G. W., E. B. B.

PENICUIK, CARLOPS AND RUTHERFORD AREA.

The area extending from Penicuik to the south end of the Mid-Lothian basin at Rutherford in Sheet 24 presents features of considerable interest owing to the attenuation of the Oil-shale group in that direction, to the thinning out and disappearance of some of the workable seams, and to the evidence of unconformable overlap of the members of this group on to the denuded platform of the Lower Old Red Sandstone beyond Rutherford. The area is also noteworthy owing to the occurrence in it, not far above the Burdiehouse Limestone in the Esk section, of a volcanic zone which is almost immediately overlain by an oil-shale of good quality, termed, for convenience of reference, the Carlops Oil-shale. No less interesting is the appearance of thin marine limestones, detected by Mr. Macconochie, beneath the Burdiehouse Limestone, in the Esk, yielding a remarkable assemblage of organic remains, comprising brachiopods, bryozoa, lamellibranchs, gasteropods and cephalopods (see description by Dr. Lee in Appendix I. p. 369).

Recently various bores have been put down in this area by Charles Edward Allan, of Stormont Castle, Belfast, who has kindly allowed the Geological Survey to examine the rock-cores and has furnished copies of the bore journals. As the boring operations are incomplete we are desired to confine ourselves at present to a brief statement of the results. The Carlops Oil-shale, of good quality, and the underlying volcanic zone have been proved to extend southwards to Rutherford. Northwards, at the Eight Mile Burn, a bore beginning near the base of the Carboniferous Limestone series passed through several oil-shales—one of good quality—together with olivine basalt lavas of the Bo'ness type, and reached an entomostracan limestone resembling the Burdiehouse Limestone of the North Esk.

The North Esk Section.—The best natural section of the Oil-shale group in the Mid-Lothian basin is to be found in the North Esk below Carlops Bridge at the southern margin of Sheet 32, where the belt of Calciferous Sandstone strata between the Pentland fault and the base of the Carboniferous Limestone series is about a quarter of a mile in breadth. Both in the North Esk and in a small tributary, named the Amazondean Burn, to the north the beds are usually inclined at high angles and are in places inverted, but the sequence is remarkably clear. During the former survey of the district, the two thin bands of limestone visible in the Esk, not far below Carlops Bridge, were regarded as representing the position of the Burdiehouse Limestone*—a view which has been adopted during the recent revision.

Beginning at Carlops Bridge where the Lower Old Red Conglomerate is seen in the river with signs of fracture evidently produced by the Pentland fault, we find the lowest visible Carboniferous strata in the stream about 120 yds. below the bridge, where they consist of

* "Geology of the Neighbourhood of Edinburgh," *Geol. Sur. Mem.*, 1861, p. 37.

pebbly sandstones, faky sandstones and shales. In a scar at the bend where the river flows to the N.N.E. these beds are overlaid by green and red clays, shales and calcareous ribs, surmounted by pebbly grits and fine conglomerate with pebbles of radiolarian chert, vein quartz and Lower Old Red Sandstone lavas, some measuring an inch across. From this point downwards for a distance of 300 yds. to the exposure of the Burdiehouse Limestone, the strata appear mainly on the eastern bank of the stream, and consist largely of green and grey sandstones, grits, shales and mudstones dipping easterly at angles varying from 30° to 50°. Intercalated in this series, we find the marine zone already referred to, about 20 ft. thick, comprising the following subdivisions in descending order :—

Thin limestone with marine fossils.
Strata.
Thin lamellibranch limestone from 6 to 8 in. thick.
Strata.
Calcareous sandstone or sandy limestone with plant remains.
Clayey shales.
Calcareous shale, about 1 ft. in thickness, highly decomposed and crowded with marine fossils, chiefly lamellibranchs.

About 20 ft. below the position of the Burdiehouse Limestone there is a band of calcareous conglomerate or sandy limestone with *Leperditia*, about 3 ft. thick, which is visible on the east bank and may probably represent the entomostracan limestone at Rutherford to the south-east, in Sheet 24.

The two bands of yellow cream-coloured limestone—the lower measuring 3 ft. and the upper 6 ft. in thickness, which in all probability represent the position of the Burdiehouse Limestone—are separated from each other by about 30 ft. of green sandstones and shales. Fossils are not abundant, but, in the upper band, entomostraca, fish remains and coprolites were obtained. After crossing about 30 ft. of strata, the volcanic zone appears in the river at the point where it changes its course towards the east. It consists of a basalt lava overlain by a thin band of tuff, 3 in. thick, crowded with fish scales, which is, in turn, succeeded by a bed of decomposing entomostracan limestone about 2 ft. thick.

At this point in the section, in a scar on the right bank, the first oil-shale (the Carlops Shale) occurs with thin intercalations of grey shale and a lenticular seam of *Spirorbis* limestone, containing entomostraca. This oil-shale is of good quality and may represent the Dunnet Shale in the Straiton section. Descending the stream for a distance of about 60 yds., we encounter a thin oil-shale of inferior quality, resting on a bed of limestone, 9 in. thick, charged with entomostraca and fish remains. A few yards farther down another prominent scar on the right bank displays a third oil-shale of poor quality, interleaved with grey shales, the beds dipping to the east at angles varying from 70° to 80°. In the middle of this zone, a thin seam of decomposing shale occurs, from which Mr. Macconochie has obtained excellent specimens of the following arthropods, determined by Dr. Peach, namely: *Cyclus testudo*, *Crangopsis eskdalensis*, *C. elegans*, *Perimecturus* and *Palæmysis*. The occurrence of this assemblage

at this locality is of special interest, as the forms are almost identical with those collected from the "Scorpion Beds" of Glencartholm, near Canonbie, in Dumfries-shire, which occur there in the higher part of the Calciferous Sandstone series.

From the third band of oil-shale down to the junction of the Amazondean Burn with the Esk, the observer crosses a succession of dark-grey and blue shales, grey and yellow sandstones, and blue calmy shales, which are followed by a fourth band of oil-shale of inferior quality resting on a thin seam of calcareous shale charged with *Pleurotomaria*. At this point the sequence is interrupted by a fault crossing the North Esk in a N.N.W. direction with a downthrow to the east, whereby the fourth seam of oil-shale with its underlying *Pleurotomaria* band has been shifted for a distance of 200 yds. to the north, reappearing in the Amazondean Burn not far above the farmhouse of that name. The rock exposures in this tributary are not continuous, but certain fossiliferous zones have been there identified by Mr. Macconochie, which have been of service for the purpose of correlation.

Descending the burn from the point near the high road, where the *Pleurotomaria* band and accompanying oil-shale occur in inverted order (I in Fig. 16, p. 184), and are followed by sandy fakes, the observer, after crossing further outcrops of grey and dark shales, meets with an exposure of calmy limestone containing cephalopods and encrinites (the Cephalopod Limestone, II in Fig. 16, p. 184), succeeded by bituminous shale. This calcareous subzone, likewise inverted, is followed by ripple-marked dark and grey fakes and by a coal formerly wrought. A few feet above this seam an important horizon is met with (III in Fig. 16, p. 184), consisting of a bed of limestone, 3 ft. thick, yielding encrinites and *Productus semireticulatus*, underlain by a thin band crowded with *Rhipidomella* [*Orthis*] and a peculiar shale charged with fragments of *Lingula* and some fish remains (the Bone Bed of the Burdiehouse Burn). As already indicated, these palæontological horizons—the encrinital limestone, the *Rhipidomella* shale and the fish band—have been detected in the same relative order in the Bilston and Burdiehouse Burns to the north (p. 170). Farther down the Amazondean Burn the *Productus* limestone is twice repeated by folding.

If we assume that the entomostracan limestone beneath the Carlops Oil-shale in the North Esk represents the Burdiehouse Limestone, then it follows that the sections just described furnish us with a more or less continuous sequence from the Burdiehouse Limestone to the Bone Bed and its overlying calcareous seam, which may be the equivalent of the Lower Abden Limestone of the Fife coast.

Nine Mile Burn.—In this stream the higher members of the Calciferous Sandstone are brought to the surface along an anticlinal fold in the overlying Carboniferous Limestone series (Chapter XI., p. 185). The sequence of the Oil-shale group on the western limb of the arch is alone exposed, as the Gilmerton Limestone and underlying Calciferous Sandstone strata on the east limb are cut out by a fault. Not far from this dislocation the *Pleurotomaria* band and its overlying oil-shale are met with in the stream dipping steeply to the W.N.W. They are followed in ascending order by

dark shales with two thin limestones, sandstones, shales and a thin coal. At the bend in the burn we pass up into the Carboniferous Limestone strata, the position of the Gilmerton Limestone being indicated by a bed of ochre, to be referred to in the sequel (Chapter XI., p. 186).

Along the narrow belt of Calciferous Sandstone strata extending northwards from the Nine Mile Burn to Glencorse, scarcely any solid rock is exposed, the stream sections being cut mainly through boulder clay. But, as already indicated, the presence of the Oil-shale group with several seams of shale has been proved by boring operations near the Eight Mile Burn. B. N. P., J. H.

Recent boring operations in the ground between Carlops and West Linton, a short distance beyond the limit of the present Map, render it advisable to call attention to the further extension southwards into the adjoining Sheet (24) of the Calciferous Sandstone strata found along the river Esk, in the section just described.

The position of the lower limestones is fixed a short distance to the east of Rutherford, the lowest bed being well exposed in Whitefield Quarry. At a point on the Deep Syke, one-third of a mile below the Carlops road, and half a mile south by west of Rutherford Mains, a hard sandy light grey limestone containing entomostraca is exposed for some distance along the bed of the stream, the beds being almost horizontal. As this entomostracan limestone may be correlated with the band which lies 20 ft. below the Burdiehouse Limestone in the Esk section referred to above, it was natural to expect the oil-shale seams of that section to occur in the ground between the outcrop of this entomostracan limestone and the marine limestones east of Rutherford. As already stated (p. 171), this expectation has been fully confirmed by bores recently put down.

Further reference may be made to a series of trial bores put down some years ago by the Clippens Oil Company in the ground immediately to the south-east of Whitefield, a mile west of Macbie Hill Station, and approximately half a mile west of the outcrop of the lowest of the Carboniferous limestones. In two of these bores, an oil-shale, 4 ft. in thickness, was proved at a depth of 8 fms.

The result of the trial borings did not at the time seem to warrant further operations, but the presence of oil-shale at this locality, in what appears to be a similar stratigraphical position to that of the shales proved at Rutherford, is interesting as indicating the probable occurrence of workable oil-shale over a considerable area between Carlops and Macbie Hill. L. W. H.

BORTHWICK, MIDDLETON AND TYNE WATER.

From evidence obtained in the ground farther to the north-east (Sheet 33), it is probable that the lowest members of the Carboniferous formation, which cross the extreme south-eastern corner of the Map, are in faulted relations with the Silurian strata along the northern face of the Moorfoot Hills.

Owing, however, to the thick covering of boulder clay, which masks the lower hill-slopes, the nature and exact position of the

boundary line between the two formations over Middleton Moor is to a certain extent conjectural.

The lowest beds of the series seen in this part of the area are well exposed along the South Middleton Burn, which joins the North Middleton Burn at Borthwick to form the Gore Water.

At the entrance of the Currie Glen, soft red and white sandstones with marly bands are seen in an old quarry in the wood, and similar rocks form the high banks of the stream within the glen on the north side. At the base of these sandstones the stream flows for some distance over the upper surface of a volcanic zone, the various members of which—loose decomposing ash, tuff with nodules of cherty rock, and a hard pillowy lava—appear at many points in the banks and bed of the burn.

Close to the sudden bend made by the stream to the south, the volcanic rocks are cut off by a small fault that crosses the bend; and about 100 yds. farther up stream they are again truncated by a more powerful dislocation running approximately east and west, with a downthrow to the south, which may be as much as 50 or 60 ft. By this fault the sandstones that overlie the volcanic zone are brought down to the bed of the burn, where they are seen in conjunction with a coarse agglomeratic ash.

Red and yellow sandstones and marls appear almost continuously along the burn from this point to Currie Farm, but the stream is flowing nearly along the strike, and no great thickness of strata is passed through. The beds are dipping N.W. to W.N.W. at low angles.

At the side of the road leading up from the stream to Currie Farm, a thin coal associated with soft yellow sandstone is exposed; while dark shales underlie the drift just above the farmhouse. The occurrence of these beds is important, as proving the red sandstones of the Currie Glen to lie within the Calciferous Sandstone series.

Returning to Borthwick and following the course of the North Middleton Burn, we find a considerable distance in which exposures of rock are few and often widely separated.

The non-appearance of the oil-shales in this position may possibly be accounted for by this discontinuity in the sections; but from the observation made by Mr. Bailey in the ground to the east, it seems more probable that they are cut out by a powerful strike-fault with a downthrow to west, whose course is indicated as crossing the stream at Borthwick.

The upper beds of the Calciferous Sandstone seen in the North Middleton Burn are, in ascending order,—red and yellow false-bedded sandstones with soft variegated marls; hard yellow gritty sandstones and coarse pebbly grits; and, immediately underlying the lowest of the Carboniferous limestones at North Middleton, sandstones and dark shales with ironstone nodules. L. W. H.

Below the Carboniferous Limestone series of Tyne Water we find a considerable thickness—probably 100 ft. at least—of alternating sandstones and marls, the former often red and the latter purplish-grey and white. C. B. C.

CHAPTER XI.

CARBONIFEROUS LIMESTONE SERIES OF THE MID-LOTHIAN BASIN.

Lower Limestone Group.

One of the most difficult questions connected with the stratigraphy of the Carboniferous Limestone series in the Mid-Lothian basin is the correlation of the lower limestones on the east side of the syncline with those on the west. The Gilmerton Limestone, which, as already stated, is taken as the base of this series on the west, has a striking resemblance lithologically to No. 2 Limestone of Tyne Water, but it is probably on a lower horizon being below the position of the North Greens Coal. For this reason different designations have been given to the lower limestones on either side. The names of the chief calcareous zones on the east are given below in descending order—

No. 3, or Chapel Point Limestone.
No. 2, or Skateraw Limestone.
No. 1, or Longcraig Limestone.*

On the west side of the basin the chief lower limestones are termed in descending order—

The Bilston Burn Limestone.
The Vexhim Upper and Lower Limestones.
The North Greens Limestone.
The Gilmerton Limestone.

The lower limestones are unusually thick at the south end of the syncline, where in some places they seem to coalesce without any intercalations of sandstone or shale.

On the western limb of the basin the Bilston Burn displays a remarkably clear section of the Lower Limestone group, and indeed of the Carboniferous Limestone series as a whole (see Fig. 15, p. 181). No such satisfactory section is to be found on the east side, but it is certain that some of the lower limestones there must differ considerably in character from those with which they correspond stratigraphically on the west.

The coast sections at Aberlady, and between Dunbar and Cockburnspath, form connecting links between the counties of Mid-Lothian and Northumberland, for part of Limestone No. 2 of Tyne Water, Mid-Lothian, is believed to correspond not only to the Skateraw Middle Limestone of Dunbar, but also to the Acre Limestone of Northumberland, and Limestone No. 1 of Tyne Water is regarded as the representative of the Longcraig

* These names are taken from the localities on the coast near Dunbar, where the supposed representatives of these limestones are best seen.

Limestones of Dunbar and also of the Eelwell Limestone of Northumberland.* C. T. C.

JOPPA, NIDDRIE AND GILMERTON AREA.

On the shore at Joppa the strata are covered by sand and drift, but indications of the limestones were found in digging the foundations of houses at the east end of the town.

A section of the group was measured in 1893, in a cross-cut mine situated a little south of the Brunstane (Burdiehouse) Burn, by the firm of Mr. William Gow, and has been communicated by Mr. Martin, Manager of Niddrie Collieries. The most important details of the section are shown below in descending order. The distance from the Carleton Coal is stated for the sake of comparison with the Gilmerton section, which is given in the sequel (p. 179).

		Ft.	In.
	Various Strata, starting from the base of the Carleton Coal and including the position of the Blue Coal	99	10
	Faky blaes	57	5
	Bilston Burn Limestone	14	9
	Blaes	15	7
	Sandstone and blaes	47	7
	Blaes	12	4
	Cement (upper vexhim limestone)	3	8
	Sandstone and blaes	71	9
	Niddrie Vexhim Coal (foul)	2	6
	Fireclay	12	4
	Coal	1	0
	Coarse sandstone	69	8
	Blaes	10	7
	Sandstone	54	11
	Blaes	23	10
North Greens Limestone.	Limestone	9	10
	Blaes	15	7
	Limestone	13	1
	Blaes	18	1
	Limestone	6	7
	Blaes	14	9
Rough Parrot Coal of Loanhead.	Coal	1	0
	Blaes	0	10
	Coal	1	6
	Sandstone	13	11
	Blaes	13	1
	North Greens Coal: Parrot	0	10
	North Greens Coal: Rough	3	9

The North Greens or Jewel Coal, shown at the bottom of this section, contains an excellent seam of Parrot and is reported to be one of the best seams in Mid-Lothian. In Brunstane Burn the "cement" band and the "coarse sandstone" of the section can be recognised, and between the burn and the sea the outcrops drawn on the map cannot be greatly in error, for Mr. Milne Home† records the occurrence of the Gilmerton and North Greens Limestones at

* W. Gunn, "Correlation of the Carboniferous Rocks of England and Scotland," *Trans. Edin. Geol. Soc.*, vol. vii. p. 361, plate xx.[a]; also *Geol. Mag.*, 1898, Dec. iv. vol. v. p. 342. C. B. Crampton, "Limestones of Aberlady, Dunbar and St. Monans," *Trans. Edin. Geol. Soc.*, vol. viii. p. 374.

† "Memoir on the Mid-Lothian and East Lothian Coal-Fields," 1839, p. 88.

Duddingston Mains, and the crops of both the North Greens and Vexhim Coals have been opened up just south of the main line of the railway. The Gilmerton Limestone was formerly worked close to Niddrie House, but the quarries are now entirely filled up. Southwards from this point to the Ferniehill Quarries there are no exposures, but the crop of the North Greens Coal is known from mining information.

Along this part of their course the various outcrops are deflected so as to run almost north and south instead of N.N.E. and S.S.W. At Ferniehill, half a mile due north of Gilmerton, the cause of the deflection becomes evident, for the Gilmerton Limestone may there be traced in a line of quarries round the nose of an anticline, the axis of which runs due north and south and pitches about 15° to the south. The Lower Limestone and Edge Coal groups between Niddrie and Ferniehill lie on the east side of this anticline, and their inclinations have been steepened and their outcrop narrowed by it. These effects are best known in the Edge Coal group, to which belong the vertical strata of Drum Quarry and the overhanging seams of No. 11 Pit (of Niddrie), just north of Edmonstone, which have been figured by Mr. Martin.*

In the Moredun Quarries, which run to the north-west near Fernieside, the Gilmerton Limestone lies on the west side of the anticline and in the most northerly quarry dips almost due west at an angle of 45°. The anticline described is not directly continued farther south than Gilmerton, but its place is taken by another starting at Hyvots Mill and running S.S.W. through the village of Pentland, the continuation of which appears in the Straiton arch (Fig. 13, p. 163). The westerly dip of the western limbs of the two anticlines is not continued up to the Pentland fault, for the beds are quickly brought up again, sometimes dipping steeply to the E.S.E., sometimes even showing a reversed dip. This is well seen in the Burdiehouse Burn south of the Gilmerton Road, where some distinctly ripple-marked flagstones overhang at an angle of 45°. Near this point a part of the Gilmerton Limestone is exposed, but, owing to a small fault, less than half of its full thickness is seen in the stream section. One result of the folding described has been the production of the shallow little basin of Gilmerton, in which we find outliers of the North Greens Coal and Limestone. The North Greens Coal in this basin has a thickness of nearly 4 ft. 6 in., of which 1 ft. 6 in. is parrot, and the rest a rough coal. It is separated from the limestone above by 17 ft. of sandstone and shale.

The Bilston Burn Limestone, which is not now visible north of Gilmerton, crops out immediately to the east of Gilmerton House, and was passed through in a pit sunk to the North Greens Coal. It is reported that the limestone is here 5 ft. thick, and is overlain by 19 ft. of calcareous shale, and that the coal, locally called the Vexhim, which lies below the limestone and is separated from it by 11 ft. of black shale, is 2 ft. 2 in. thick.

The following section of the group as developed at Gilmerton is based on information given by Mr. Marshall, Mining Engineer, Edinburgh, except as regards the thicknesses below the North Greens

* "The Mid-Lothian Coal Basin," *Trans. Min. Inst. Scot.*, vol. xv. pt. iii. p. 164.

Coal, which have been obtained by protraction from the surface. The positions of the Carleton and Blue Coals are given so as to allow of comparison with both the Niddrie and Loanhead sections:—

		Ft.	In.
	CARLETON COAL	5	6
	Strata	84	0
	BLUE COAL	7	0
	Strata *	90	0
BILSTON BURN LIMESTONE.	LIMESTONE blaes	19	0
	LIMESTONE	5	0
	Blaes	11	0
	COAL, VEXHIM of Gilmerton	2	2
	Blaes	4	0
	COAL	1	2
	Freestone	11	0
	Blaes	3	0
	Sandstone	54	6
	Blaes	2	6
	LIMESTONE blaes (UPPER VEXHIM LIMESTONE)	8	3
	COAL	2	0
	Fakes	7	6
	Blaes	1	6
	Freestone post and fakes	20	6
	Blaes with ironstone balls	18	6
	Fakes	2	0
	LIMESTONE blaes (LOWER VEXHIM LIMESTONE)	6	0
	Blaes	1	6
	COAL } VEXHIM of Niddrie {	1	0
	COAL, fine splint } VEXHIM of Niddrie {	2	0
	Freestone and fakes	4	0
	Blaes	28	6
	Carle †	1	0
	COAL	0	9
	Blaes	0	6
	Red sandstone	146	6
NORTH GREENS LIMESTONE.	Blaes	91	3
	Blaes	57	0
	LIMESTONE	6	0
	Blaes	3	0
	Sandstone	1	3
	Clay	0	9
	Freestone and fakes	7	3
	Blaes	1	0
	Sandstone (fakes)	1	0
	Blaes	6	0
NORTH GREENS COAL.	PARROT COAL	1	4
	Hard band (ironstone ?)	0	6
	Fireclay	0	9
	PARROT and ROUGH COAL	3	0
	Strata	110	0
	Calcareous blaes	10	0
	GILMERTON LIMESTONE	60	0

It will be seen that a small group of coals occurs between the North Greens and Bilston Burn Limestones. The name Vexhim has been applied rather loosely in different localities to different coals of this group. Thus the Niddrie Vexhim is obviously represented at Gilmerton by the 3-ft. coal which lies about 35 ft. above the thick red sandstone. The latter constitutes a good horizon and

* The section between these beds and the base of the North Greens Coal is taken from the old Engine Pit near Gilmerton House.

† This word is not known among miners. Perhaps it is a clerical error for "clay."

is known to extend from Niddrie to Gilmerton and thence to the Bilston Burn. The word blaes is often applied to argillaceous limestone as well as shale, and it is probable that in the above section some of the blaes recorded represents argillaceous limestone, for the limestone portions of the North Greens and Bilston Burn seams, as shown in the section, are much thinner than they are in Bilston Burn.

The only accessible exposures of the group are those in the Gilmerton Burn and in the various quarries in the Gilmerton Limestone.

The bottom portion of the Gilmerton Limestone, 10 ft. in thickness, is largely made up of the remains of encrinites. It was followed from the quarries underground in mines and is the only part which was ever quarried for burning. Above the 50 ft. of evenly bedded grey limestones, which follow the mined portion, we find about 10 ft. of dark calcareous shales which have yielded a considerable number of marine fossils. The shale is succeeded by a persistent group of flaggy sandstones.

Although its position is not given in the above section a well-known blackband ironstone lies a little above the North Greens Coal, and contains fish remains. Dr. Traquair* states that the fauna indicates estuarine conditions, and resembles that of the Wardie Shales and the Oil-Shales, but differs entirely from that of the marine limestones. The band has also furnished the remains of several labyrinthodonts. W. G., E. B. B.

LOANHEAD, BILSTON BURN AND MAURICEWOOD AREA.

Three miles south of Gilmerton an excellent section of the Lower Limestone group is exposed in the Bilston Burn (Fig. 15), where the strata generally dip to the south-east at angles varying from 40° to 48°.

In this stream immediately to the west of Pathhead we find a series of coarse ochre beds which, in the past, were worked for ochre. The largest of these, 21½ ft. thick, is the representative of the Gilmerton Limestone, as already shown (p. 170). From information snpplied by an old miner it appears that a limestone, which was identified as the Gilmerton Limestone, was quarried by him close to the farmhouse north of the stream and in the same line of strike as the beds of ochre. This statement is corroborated by old limestone workings at this spot, and additional evidence is thus furnished of the correlation of the Gilmerton Limestone with the ochre bed in Bilston Burn. In this connection it is interesting to note that in the Nine Mile Burn section, 7½ miles to the south-west, the position of the Gilmerton Limestone is also occupied by an ochre bed of which 20 ft. is exposed (p. 186).

Between Bilston Burn and Penicuik the Gilmerton Limestone is not visible, but in a bore to the south-west of Mauricewood Colliery it has been proved to have a thickness of 48 ft., and 100 ft. above it lies the North Greens Coal. A thin limestone is intercalated in the strata between these two horizons (see Fig. 15).

*"Distribution of Fossil Fish Remains in the Carboniferous Rocks of the Edinburgh District," *Trans. Roy. Soc. Edin.*, 1903, vol. xl. pt. iii. p. 694.

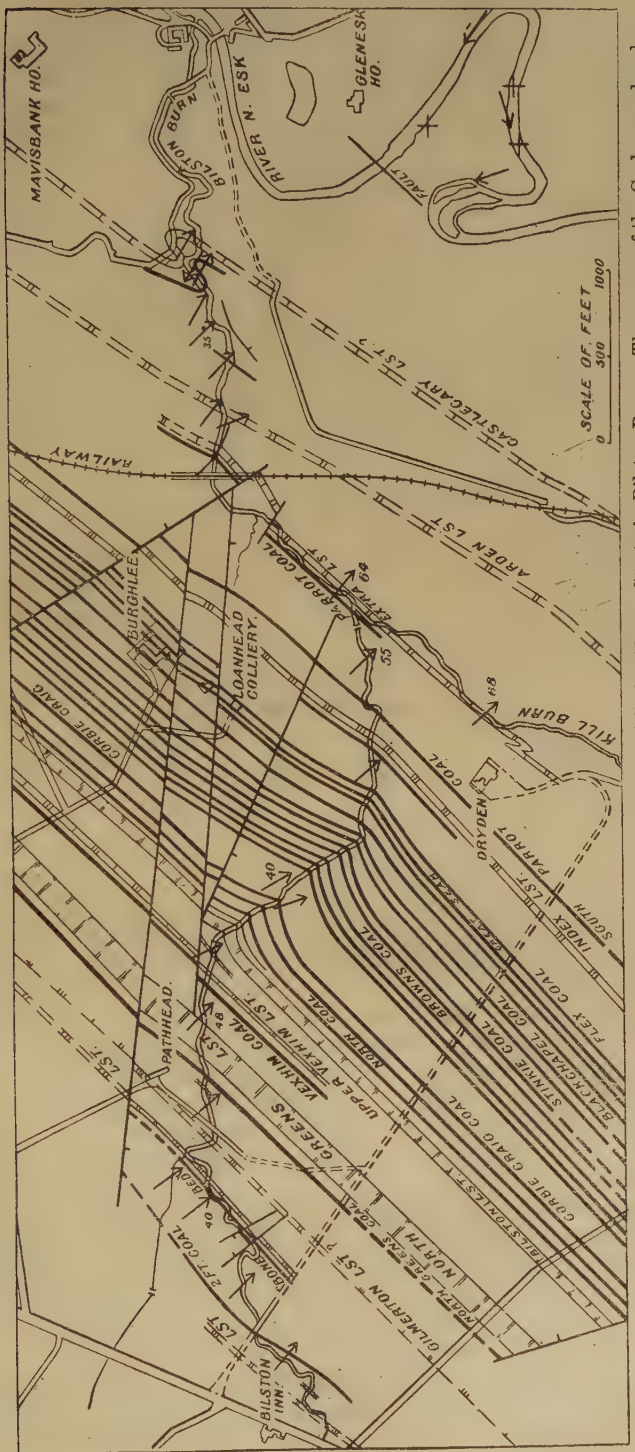

FIG. 15.—Map on the scale of 6 inches to 1 mile, showing the sequence of Carboniferous Strata in Bilston Burn. The names of the Coals are placed above the seams, with the exception of the Vexhim and Parrot.

In the past the well-known North Greens Coal was extensively worked in the Gilmerton field, and has also been wrought to crop from the Sheriffhall and Burdiehouse fault to within a short distance of the village of Loanhead. In the Bilston Burn, in the hollow 70 yds. S.S.E. of Pathhead farmhouse, it was opened up some years ago by the Shotts Iron Co., where it furnished the following section :—

	Ft.
Roof, sandstone.	
Coal, duffy	1
Coal	4½
Pavement, grey fakes.	

In the Bilston Burn about 48 ft. above the North Greens Coal there is a Rough Parrot Coal, 2 ft. 4 in. thick.

At Loanhead this seam was worked in the Ramsay Pit till quite recently by means of a stone mine driven from the North Coal along the "veese" of the Edgefield fault, from which the following sections were obtained :—

Section, North Side Working.

	Ft.	In.
Roof, blaes.		
Coal, duffy	0	9
„ Parrot	0	3
„ Splint	0	9
„ Free	3	3
	5	0

Section, South Side Working.

	Ft.	In.
Roof, blaes.		
Coal, Inferior	0	2
„ Free	0	6
„ Splint	1	0
„ Free	2	2
	3	10

A comparison of the two sections shows that to the south-west the parrot in this seam disappears, and the bottom coal at the same time becomes thinner.

The Rough Parrot Seam above the North Greens Coal in the Bilston Burn was opened out in 1864 at the Fountain close to the old limestone quarry, by a mine driven into the seam for about 40 ft., and then wrought level course a few fathoms each way. This coal was identified as the Parrot which was wrought at that date at Gilmerton about 30 ft. above the North Greens, according to John Ainslie's plan.

The North Greens Coal has never been worked between Loanhead and the Glencorse Burn. To the east of the church on the south bank of this stream there are traces of coal working. To the south-west of Mauricewood Colliery the bore (already mentioned), which proved the Gilmerton Limestone, also passed through this seam and found it to be 4 ft. thick.

Between the Engine Pit near Gilmerton House and Edgefield the North Greens Limestone is not visible, but in the railway cutting below the farm a good section is exposed. At this point the lime-

stone, which is here a light grey encrinital rock, 76 ft. thick, is 12 ft. 6 in. above the North Greens Coal, and is overlain by 120 ft. of red, white and mottled sandstone. A considerable portion of the limestone in the cutting is calmy and might be called limy blaes.

In the Bilston Burn (Fig. 15) about 61 ft. of strata separate the North Greens Coal and Limestone. In the stream the latter bed consists of about 90 ft. of dark limestone, limy fakes and blaes, all very fossiliferous. On the north side of the burn and in the fields above, the limestone was at one time quarried. This broad outcrop, with a 3-ft. ochre bed at top, is surmounted by 67 ft. of red, white, yellow and mottled sandstone (North Greens Sandstone) similar to that in the railway cutting just described.

Between the Bilston Burn and Glencorse Burn the ground is covered with drift. On the west side of the Edinburgh and Penicuik road at Gowklie Moss, about a mile south from Bilston Burn, a limestone has been quarried, but its exact horizon is doubtful.*

In the Glencorse Burn, 150 yds. above the Mill, the following section is exposed :—

	Ft.	In.
LIMESTONE	3–4	0
Blaes and sandstone	32	0
LIMESTONE	8	0
Gap	75	0
Encrinital LIMESTONE	20	0
Blaes	7	6
Ironstone	0	5
Blaes	22	0
Sandstone	7	10
Gap (including position of NORTH GREENS COAL)	8	0
Blaes	5	2

Between this point and Penicuik the North Greens Limestone has been proved in a bore on the south side of the Cuiken Burn to have a thickness of 10 ft. and to lie 40 ft. above the North Greens Coal.

The Vexhim Coal of Loanhead and Niddrie lies a little above the North Greens Sandstone and is seen on the south side of the quarry close to Gilmerton House. It is a soft inferior coal, which has been wrought along the crop to Laverock Hall, where there is a mine, not being worked at present but formerly used to supply fuel to the Burdiehouse Limeworks. On the south side of the Sheriffhall fault the Upper Vexhim Limestone is exposed in the Edgefield railway cutting, where it consists of 4 ft. of limestone and 2 ft. of limy fakes. In the Bilston Burn the coal is 2 ft. 8 in. thick and is separated by 38 ft. of strata from the Upper Vexhim Limestone. It here lies 277 ft. above the North Greens Coal. Between Bilston Burn and Penicuik this coal and limestone have not been found. Ascending in the sequence we find the two Vexhim Limestones between the Vexhim Coal and Bilston Burn Limestone, a fact worthy of note as showing the marked development of calcareous zones in the Lower Limestone group.

The Bilston Burn Limestone is not now seen at Gilmerton but was formerly worked in a quarry a little to the east of the present

* "Geology of the Neighbourhood of Edinburgh," *Geol. Sur. Mem.*, p. 78.

sandstone quarry at Gilmerton House. To the south-west it is first exposed in the Bilston Burn (Fig. 15) where its full thickness is about 50 ft., the bottom portion being a grey coralline limestone in beds which vary from 2 to 6 ft. in thickness, with thin partings of shale. The top bed is more impure and sandy and shows good *Cauda-galli* markings at the base. It lies about 50 ft. above the Upper Vexhim Limestone.

Between Mauricewood and Mauricewood Pit this limestone has been uncovered and proved to be 180 ft. below the North Coal. To the west of Cuiken the position of this bed has been laid down on the map from boring information.

In the Bilston Burn the thin limestone, 1 ft. 8 in. thick, which lies 41 ft. above the thick limestone just described, has been taken as the top of the Lower Limestone group.

AREA BETWEEN PENICUIK AND CARLOPS.

By far the best section of the Lower Limestone group between Penicuik and the village of Carlops is to be found in Habbie's Howe

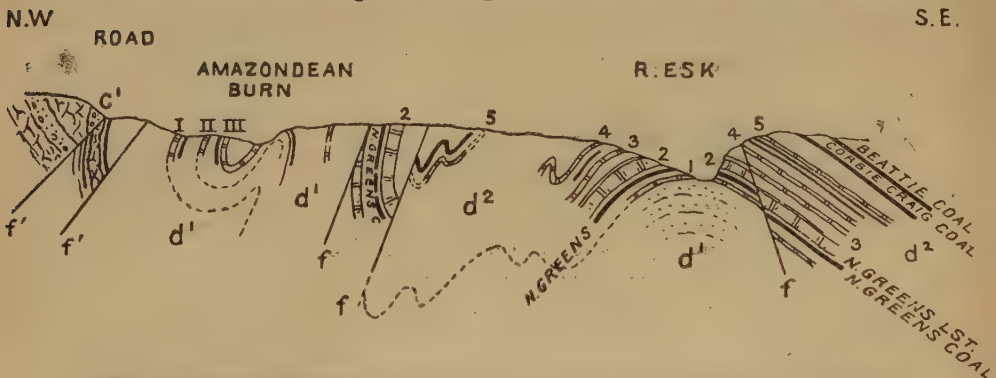

FIG. 16.—Section of Calciferous Sandstone and Lower Limestone Group in Amazondean Burn and in Habbie's Howe, North Esk, Carlops.

on the North Esk, where the sequence of limestones is clearly displayed.

Below Newhall House the strata dip steadily to the east, but are thrown into a series of folds as they approach the Pentland fault on the west, an anticlinal fold to the west of Newhall being succeeded by a compound syncline whose western limb is slightly inverted, the bed dipping steeply to the west. These folds are further modified by several faults, some of which are reversed.

In the two sections about to be described, no less than five distinct bands of limestone have been recognised. The highest beds are comparatively thin, and it is evident that the upper bands, which, in the sequel, will be shown to coalesce at the south end of the basin, are here split up by the intercalation of non-calcareous strata.

The top limestone (No. 5 in Fig. 16) crosses the Esk immediately below Newhall House, about 70 yds. above the footbridge. It is a dark calmy rock (14 inches thick), the upper portion crowded with small Producti (*P. semireticulatus*). It is succeeded by two thin

coals, presumably in the position of the Vexhim Coals. From the point where the stream makes a sudden bend to the north, it flows for some distance along the strike of the next limestone (No. 4 in Fig. 16), which is seen in the right-hand bank. At the next bend, a rusty-weathering limestone, 6 to 8 ft. thick (No. 3 in Fig. 16), appears in the bed of the stream, while a thicker band—the North Greens Limestone—(No. 2 in Fig. 16) is seen in the bank on the north side. At the next footbridge a small fault with a downthrow to the east crosses the stream and brings up this limestone (No. 2) on the high southern bank where it forms a steep crag underlain by the North Greens Coal.

Immediately above the bridge the river is flowing over the crest of the undenuded portion of the anticlinal dome, occupied by the lowest or Gilmerton Limestone and a small inlier of the underlying Calciferous Sandstone strata. On the west side of the fold the No. 2 band appears again, forming the linn, and is seen in the banks on either side of the stream at Peggy's Pool. This band is here 50 ft. in thickness, the lower portion thick-bedded and very fossiliferous, the upper 20 or 30 ft. made up of limestone bands and calcareous shale. A line of old pits to the south-west of the river shows where this limestone was at one time quarried along the outcrop.

Between the linn and the next sharp bend of the stream, Nos. 3 and 4 limestones can be detected, but are badly exposed. The strata are now concealed for some distance until on the steep northern bank, about 40 yds. below Mill Bridge, a thin limestone—probably No. 5—is sharply folded with one of the lower Edge Coals. The strata beneath are now partly faulted out, and the next recognisable bed on the west side of the disturbance is the North Greens Limestone (No. 2), followed by the North Greens Coal and an underlying white ganister. This limestone has been quarried immediately above the bridge.

The beds are now vertical or even inverted and dipping slightly to the west. The lowest (Gilmerton) Limestone does not appear in the river, being cut out by a small fault, but is seen in the small side stream on the south bank.

Between this point and the foot of the Amazondean Burn, the section is occupied by sandstones and dark shales with lenticular masses of encrinital limestone, all belonging to the Calciferous Sandstone series.

The ground to the north of the Esk is drift covered, and the limestones are next seen in the Nine Mile Burn, below the Carlops and Penicuik road. The structure exhibited in this section is a modification of that found at Habbie's Howe. As in the latter locality, an anticline is followed by a syncline, but here the eastern limb of the former is inverted, and the centre of the fold traversed by a fault throwing down to the east; while the syncline is truncated on the west by the Pentland fault.

The first limestone seen in the stream, at a point 500 yds. south-east of the Carlops road, is a yellow encrinital band, 4 ft. thick, which forms a small waterfall. This is No. 4 of the Habbie's Howe section, No. 5 being cut out by a small fault which crosses the stream immediately above the outcrop of the lowest (North and

South) Coal. Above this fault the beds dip steeply to the west, and follow one another up the stream in apparently inverted order. The yellow encrinite band is succeeded by dark shales; a limestone in two bands (No. 3), separated by shales; a thick sandstone; and No. 2, or the North Greens Limestone, below which the North Greens Coal, 2 ft. thick, was at one time wrought but is now no longer visible.

The Gilmerton Limestone and underlying Calciferous Sandstone strata are cut out by a fault which crosses the burn 60 yds. above No. 2 Limestone.

Two hundred yards below the road we pass again into Carboniferous Limestone strata, the position of the Gilmerton Limestone being indicated—as in the Bilston Burn—by a yellow ochre bed, 20 ft. of which is exposed. The base is filled in with a siliceous network containing casts of Producti, Encrinites and branching corals. Beneath this ochre bed is a 1-ft. coal, resting upon a fireclay.

A higher coal seam, which may be regarded as the North Greens Coal, has been wrought at Gardenfield, 100 yds. higher up the stream, and blocks of limestone seen in the burn suggest that this coal is overlain by a limestone not visible in place—No. 2, or North Greens Limestone. A limestone laid bare during the building of the school at the roadside, 100 yds. to the west, may represent either a higher bed or a repetition of the North Greens on the other side of the fold.

Between this point and the Nine Mile Burn Inn the Carboniferous Limestone is cut off by the Pentland fault, the intervening ground being obscured by drift.

Between this section and the Cornton Burn, where these strata are next observed, the beds are interrupted by the fault or faults which run north-west and south-east through the Brunston Colliery.

In the Cornton Burn the lowest limestone and the North Greens Coal are concealed by drift.

The North Greens Limestone is here seen in two bands, separated by a few feet of shale. The lower bed is about 25 ft. in thickness, a very fossiliferous encrinital rock. Above the upper calcareous band, a good coal, 15 in., crops out in the burn, and, being correlated with the Vexhim Coal of Niddrie, fixes the position of the next succeeding limestone, a grey crystalline rock with large Encrinites, as the Vexhim Limestone.

There are no further exposures of the Lower Limestones between this point and Carsewell. L. W. H.

MIDDLETON, ESPERSTON, TEMPLE AND MOUNT LOTHIAN AREA.

The base of the lower group of Carboniferous limestones crosses the North Middleton Burn about 60 yds. below the bridge at North Middleton, and a good section of the lower portion of the lowest band of limestone is exposed along the stream between this point and the bridge at Guildie Howes.

The bottom beds, which rest upon sandstone and dark shale with ironstone nodules, are composed of a dark, blue-grey, encrinital limestone. To this succeeds immediately above the cauld at the bridge

a thick-bedded yellow-weathering limestone with a strong *Lithostrotion* band. This coralline limestone is seen at short intervals along the stream to a point 60 to 70 yds. below the upper bridge. The strata are dipping westwards across the burn at 10°, and though there is one break in the section where a limestone slightly different in character appears, it is probable that between the cauld and the upper bridge the stream is flowing over nearly the same beds, and that the whole thickness of limestone passed through in this section may not exceed 20 ft.

The strike of the limestone in the stream carries it up to the old Middleton Quarry, at a slightly higher elevation on the south side of the road, where higher beds are exposed. The top of this quarry is a concretionary limestone which closely resembles the concretionary rock that forms the upper part of the section in the Catcune Quarry and of the middle limestone of the Tyne Water. Immediately below this concretionary limestone, which averages 15 ft. in thickness, is a band with large scattered *Productus giganteus* followed by a shaly bed with large cup-corals. Below this come 12 ft. of flaggy limestone with shaly seams to the bottom of the quarry.

A more complete section of these limestones, with the overlying strata, can be studied in the New Middleton Quarry, half a mile farther to the south.

In the tramway cutting which leads into the quarry from the north, a thin limestone containing Producti, Encrinites, *Syringopora*, *Alveolites* and *Cauda-galli* markings is exposed at the bridge. This band can be correlated with a persistent thin limestone that has been traced between the middle and upper bands in the ground farther to the east.

The complete section is as follows, in descending order:—

Tramway Cutting.

		Ft.
No. 3 LIMESTONE	LIMESTONE	2–3 (seen)
	Dark shale and thin coal ..	?
	Yellow and white sandstone ..	?
	Black shale with coaly seam ..	6
	White fireclay	2–3

Continued in Quarry Section.

No. 2 LIMESTONE (equivalent of SKATERAW LIMESTONE) and	Thick-bedded and concretionary LIMESTONE with dark shaly partings	16
	Thin-bedded flaggy and faky LIMESTONE	12–16
No. 1 LIMESTONE (equivalent of LONGCRAIG LIMESTONE).	Thick-bedded grey, yellow-weathering LIMESTONE with cup-corals, *Lithostrotion* and Encrinite bands: lowest layers thinner with dark shaly partings	15–18 (bottom not seen)
	Maximum thickness of LIMESTONE now exposed in quarry	50

The strata dip N.W. to N.N.W. at 10° to 15°, and the rock has been continuously quarried up the hill-slope to the south-east for a distance of 400 yds. The whole thickness of limestone represented in these workings must be nearly 100 ft. In the old quarries in the plantation on the top of the hill the limestone is capped with a few feet of faky sandstone.

The beds immediately beneath this cover differ somewhat in character from those at the top of the Middleton Quarry, and it is possible that the limestone of that quarry is here separated from a lower limestone by a few feet of non-calcareous sediment, which there is not sufficient evidence to trace for any distance further along the strike.

A limestone with the characteristic concretionary top and *Productus giganteus* band of the Catcune and Middleton Quarries appears again in the North Middleton Burn a quarter of a mile to the south of Esperston. As this rock is followed up the stream it appears to pass continuously into a thick-bedded, yellow-weathering, encrinital limestone similar to that of the stream section above North Middleton, which is succeeded below by variegated sandstones and shales.

The most obvious inference from the evidence afforded by the sections described above is, that, while the upper part of the Middleton Quarry represents the second limestone of the Tyne Water (Skateraw), and the limestones seen in the burn at North Middleton the lowest or Longcraig, in this particular area these two lower limestones have by the thinning out or complete disappearance of the intervening sediments nearly or entirely coalesced; and that their combined thickness may here be considerably over 100 ft.

It should be noted that in this part of the basin there is no evidence of any coal in the position of the North Greens seam, which on the west side lies between the two lower limestones—the Gilmerton and North Greens.

Returning to the stream section at Esperston Farm, we find the same succession above the concretionary limestone as that seen in the tramway cutting. Immediately above the farm, and again 300 yds. farther down, the stream is flowing over a gentle dip slope of the third limestone with *Cauda-galli*, described in a former paragraph. Above this limestone in the stream bank is seen a fireclay and 16 to 18 in. splint coal (Vexhim Coal position), which is immediately followed by the base of the highest or Esperston Limestone.

The Esperston Limestone is well displayed in the large quarries which extend for half a mile south-west from the Arniston Limeworks, and are at the present time extensively wrought for building and agricultural purposes.

The section seen in the southern working face is as follows:—

		Ft.
Esperston Quarry.	Yellow, brown-weathering sandstone	4–6
	Yellow and dark shales	
	Hard compact evenly-bedded blue LIMESTONE, in beds 1 to 2 ft. thick, but thicker towards base	20
	Thin shaly partings	(bottom not seen in quarry)

The characteristic fossils of the upper part of this limestone are, *Pinna flabelliformis, P. mutica, Spirifer trigonalis, Productus punctatus, Bellerophon, Syringopora, Cauda-galli* markings.

The beds are lying at a very low angle, and sometimes appear to be almost flat, and the same limestone again appears in the bank on the north side of the deep valley below the old limekilns.

In the area to the west of Esperston, along the southern margin of this Map, it has been found impossible, on account of the heavy covering of glacial deposits, to separate the different limestones of this group. The area tinted with the limestone colour represents the calcareous group as a whole, and does not imply that all the ground thus coloured is occupied by solid limestone.

The limestone exposed in the bank of Rosebery Reservoir (South Esk) at low water is probably the lowest bed, representing the rock of Middleton Quarry. It is overlain by sandstone, fireclay and a thin coal. This coal was at one time wrought at Fountainside, but was found to be not continuous owing to the underlying and overlying limestones coming together. L. W. H.

The top of the next higher limestone is seen in the bed of the South Esk just below the outfall of the Rosebery Reservoir. It probably represents the limestone quarried at Esperston and Limestone No. 3 of Tyne Water. Some distance above it there is a thin calcareous band, passing in places into a fossiliferous limestone, believed to be the representative of the limestone which was struck at the bottom of No. 17 bore of the Arniston Coal Company, where it had a coal with "parrot" close above it. This thin limestone is well seen in the South Esk above Temple, and also as an inlier in the bed of the river between Temple and the junction of the South Esk with Redside Burn.

The section below this thin limestone is somewhat as follows:—

	Ft.	In.
Shale	10	0
COAL	from 9 in. to 0	6
Shale	4	0
COAL	0	6
Dark shale and ganister	7	0
Thick red speckled sandstone with dark shale and flaggy sandstone	from 30 ft. to 35	0
LIMESTONE (Esperston)		

C. B. C.

An increase in the thickness of the beds takes place where the limestones mantle on the north and east round the Lower Silurian rocks, a small portion of which project into this Sheet near Venture Fair.

These limestones were at one time extensively wrought in the neighbourhood of Mount Lothian, and also at the Side Limeworks near Fountainside, where the following section, now much obscured, was exposed:—

	Ft.
Sandstone	
Concretionary LIMESTONE bands	
LIMESTONE	7
Calcareous shale	
LIMESTONE	9

The rock quarried at Hillhead and Fountainbridge (Sheet 24) is probably the lowest bed of the series.

A thick limestone with a concretionary top, which may be correlated with the Upper Middleton or Catcune band, is seen at several places along the line of outcrop between Rosebery Reservoir and Mount Lothian, and has been wrought at the Fullarton Quarries, where the section shows—

	Ft.
1. Concretionary flaggy grey LIMESTONE with shaly partings	16–20
2. Hard grey encrinite LIMESTONE in thick beds (worked by a mine)	16 (bottom not seen)

The limestone contains *Saccamina carteri*, Crinoids, *Fenestella* and corals, *Productus longispinus, P. punctatus, Spirifer*, etc. The dip is north-east at 8° to 10°.

In the old quarries at Mount Lothian, now almost entirely grassed over, a hard grey encrinital limestone is seen, the beds lying almost flat or dipping N.N.E. at low angles. They probably represent the lower beds of the Fullarton section, the whole of the intervening ground being presumably occupied by limestone.

There is sufficient evidence immediately to the west of Mount Lothian to differentiate two limestone outcrops, separated by a belt of sandstone. At Herbershaw the limestones are finally cut off on the west by the fault which forms the eastern boundary of the basin in the ground to the south. The extension of this fault into the present area has been proved in the bores put down in the neighbourhood of Venture Fair. The limestones reappear on the west side of the fault between Venture Fair and Mosshouses, where they were formerly worked, but are now no longer visible.

The evidence obtained in the ground farther to the south, a short distance beyond the limits of this Map (in Sheet 24), shows a certain amount of change in the sedimentation of the Lower Limestone group.

There is, indeed, a general resemblance in character between the second or higher limestone in the south-east part of the basin and that of the Middleton Quarry; but with regard to fossil contents, and, in the case of the other limestones, to lithological characters, it is no longer possible to correlate them with any certainty with the limestones on the east side of the area. The third or highest limestone does not appear to be always present, and where it occurs is of variable thickness, never exceeding 4 or 5 ft., and different in character from the Esperston Limestone. There seems to be more affinity between these limestones and those on the west side of the basin already described. L. W. H.

TYNE WATER AND GORE WATER AREA.

Owing to the low angle of dip—in a general north-westerly direction—the lower limestones and the beds between them extend in the Tyne Water over a considerable distance—from Ford (Sheet 33) to Crichton Castle, near the head of the Tyne. The same limestones continue south-west and cross the Gore Water between Fushiebridge and Borthwick, but owing to the covering of drift they are only seen

in one or two places outside the Tyne valley. From the exposures in the Tyne valley and in the Vogrie burn the following generalised section, in descending order, has been constructed:—

		Ft.	In.
	PARROT COAL—		
	Yellow sandstone	10	0
	Black and blue shale* (blaes)	6	0
	Well-bedded rather calmy LIMESTONE with few crinoids and flattened oval concretions. Seen in Vogrie burn and quarry at Ford	18	0
	Black and blue shale and white and yellow sandstones	20	0
	Very ferruginous LIMESTONE, with encrinites	1	0
	Sandy blue shale and hard sandstone	10	0
	Impure dark-blue LIMESTONE ..perhaps	5	0
	Sandstone, shale and hard white ganister with thin COAL ..perhaps	10	0
	Ferruginous LIMESTONE with *Syringopora* and *Cauda-galli*	4	0
	Alternating thin yellow sandstone and "inky" shale, with fireclay and a 1-ft. coal. Seen in quarry at Currie Lee	15	0
NO. 2 OR SKATERAW LIMESTONE.	Hard LIMESTONE in two beds	8	0
	LIMESTONE full of black concretions, probably pyritous, and with many fossils, including *Pinna*, *Spirifer*, *Productus* and *Fenestella*	42	0
	Well seen in quarries at Currie Lee and Catcune, and in a railway cutting near Fushiebridge		
	Calmy even-bedded LIMESTONE with partings of "inky" calcareous shale		
	Hard crystalline LIMESTONE, often worked by mines. Usually with a band of *Saccamina carteri* near the top	15	0
	Strata including a considerable proportion of yellow micaceous sandstone and a thin COAL near the top ..at least	50	0
NO. 1 OR LONGCRAIG LIMESTONE.	LIMESTONE concretionary, with many fossils. Large simple corals not uncommon. The lower part full of *Lithostrotion*. The bottom seen at Crichton Castle	25	0

It is believed that the Limestone No. 2, estimated to be 65 ft. thick in all, corresponds to the Middle Skateraw Limestone of the coast section east of Dunbar, together with some of the overlying beds. C. B. C.

THE ROMAN CAMP, FORDEL AND COUSLAND AREA.

Beds belonging to the Lower Limestone group rise to the surface, in the anticlinal ridge that separates the Mid-Lothian and East Lothian coal-fields. They appear in two inlying areas—one at the Roman Camp and the other farther north between Coldwells and Cousland. But the lowest limestone, No. 1 of Tyne Water, probably does not emerge at the surface anywhere in this ridge, and the beds which lie below Limestone No. 2 are only known to come up to the base of the drift in one small area near D'Arcy farm, where a boring which started just below this limestone is said to have gone through a coal near the top, and to have pierced more than 100 ft. of beds below the coal without reaching any lower limestone. It

* This and the overlying beds in this section are classed with the Edge Coal series.

seems, therefore, that near D'Arcy the interval that separates Limestones No. 1 and No. 2 must be about twice as great as in the Tyne Water.

The Limestone No. 2 of Tyne Water has been extensively worked by means of mines at Mayfield, D'Arcy, Chalkieside and Cousland. The lower crystalline or mined portion and the overlying calmy portion, which is well exposed in the Mayfield Quarries, are separated from one another by a band or bands of calcareous dark-coloured shale. This shale can be traced as far north as Cousland, and probably represents a portion of the thick black shale, which, in some other districts, takes the place of the upper calmy portion of the limestone.

A dark shale with sandstone bands and a thin coal constantly overlie the Limestone No. 2.

The limestone of the Hillhead and Blinkbonny Quarries, at the southern end of the Roman Camp ridge, may possibly overlie the D'Arcy Limestone and correspond to one of the limestones overlying No. 2 Limestone in the Tyne Water, though in the quarries north-west of Hillhead it is at least 30 ft. thick. Bores, called the Camp Bores Nos. 1, 2 and 3, show that there are about 80 ft. of strata between the Parrot Coal and the Hillhead Limestone, and that these strata include two thin limestones from four to five feet thick. In the shaft of the Lady Victoria Pit, Newtongrange, a good limestone, slightly over five feet thick, containing crinoids, and underlain by 19 in. of calcareous shale, was cut at a depth of about 12 ft. below the Parrot Coal. About 25 ft. below the base of this little limestone there is another thicker limestone, about 51 ft. thick, which is perhaps continuous with the limestone quarried at Hillhead.

Both the Hillhead and the D'Arcy Limestones are much obscured by drift. The former limestone is probably truncated on the south side by a fault, striking slightly south of west and with a downthrow to the south, which has been proved in the adjacent measures of the Edge Coal group. The evidence suggests that, in a northerly direction, the outcrop of the Hillhead Limestone extends up to that of the D'Arcy Limestone at Mansfield, the two being there separated by a fault striking north-east, which has a considerable downthrow to the south-east, as shown on the map (32). The Hillhead Limestone is nowhere seen distinctly overlying, or dipping above, the D'Arcy Limestone, but about a quarter of a mile W.S.W., and again about 170 yds. E.N.E. of Lawfield, there are indications of small old quarries which lie outside the line taken as the top of the D'Arcy Limestone and may be in the Hillhead Limestone.

It is supposed that the sandstone in the wood at Hillhead lies above the limestone and that it forms part of a little outlier. In one of the quarries in the western part of the wood the limestone is sharply folded and dips steeply east for a little space, and perhaps there is a parallel fold of the same kind a little farther east. Near the fold exposed there is also a fault plane, inclining west at 25°, but the amount of disruption along the plane is not clear.

About 90 yds. east of the bridge over the railway cutting at Crossgatehall, a nearly vertical N.N.E. fault occurs, on the west side of which are beds belonging to the Edge Coal group, while on the east side comes a set of sandstones, shales, thin limestones and coals.

A little below one of the limestones a parrot shale, 8 ft. thick, is observed. It appears necessary to suppose that all the beds exposed on the east of the fault are higher in stratigraphical position than the thick limestone that has been quarried a little south of the cutting, but lower than the Parrot Coal, which lies near the base of the Edge Coals. If this be the case, the beds must experience a great change in the interval, of about four miles, which intervenes between Crossgatehall and the Tyne Water near Vogrie. In the latter district the strata between the Parrot Coal and the thick limestone, No. 2, are estimated to be about 100 ft. thick and include four limestones, varying in thickness from 18 ft. to 1 ft., while at Crossgatehall the beds seen east of the large fault are more than 300 ft. thick and include four thin limestones as well as a calcareous ironstone.

The strata on the east side of the fault in the railway cutting at Crossgatehall are confused in places with small dislocations, some of them reversed, and with occasional sharp folds near one of the fractures, but the general succession is tolerably clear, and is somewhat as given below, beginning at the top:—

	Ft.	In.
Sandstone	12	0
Shale	9	0
LIMESTONE	1	6
COAL and sandstone partly combined into a breccia-form bed	0	6
Grey clay	10	0
Sandstone..at least	120	0
LIMESTONE	6	0
Mostly shale, with ironstone nodules	8	3
Parrot shale	0	3
Shale	1	0
COAL	0	6
Shale	4	0
Parrot shale	8	0
Shale	4	0
Calcareous ironstone	0	7
Shale, with ironstone balls	10	0
Sandstone	14	0
Shale	5	0
Sandstone	10	0
Shaly sandstone	5	0
Shale and ironstone	15	0
Impure LIMESTONE	1	3
Shale and clay	2	0
Alternations of sandstone and shale	18	0
Shale	7	0
LIMESTONE	5	0
Blue clay	3	0
COAL	0	10
Clay, with sandstone bands	12	0
Sandstone..more than	30	0

It seems probable that the thick limestone of Hillhead splits up in a northerly direction into several thinner beds—represented by some of those in the railway cutting—which are separated in places by considerable intercalations of sandstone and shale.

About a third of a mile south-east of the Crossgatehall railway bridge a boring is said to have passed through three limestones and

a coal, 19 in. thick, about 45 ft. below the bottom limestone. These limestones must be separated from the Cousland Limestone on their eastern side by a considerable fault, striking north-east and with a downthrow to the north-west, and it is probable that in the undisturbed section they lie above this limestone.

AREA NORTH OF CROSSGATEHALL.

The Roman Camp anticline extends northwards almost to the sea at Prestonpans. Along the axis of this anticline the bands of limestone which are seen in the railway cutting at Crossgatehall must be near the surface for a considerable distance, but it is uncertain how far their actual outcrops continue. In a bore at Queen Mary's Mount, a band of limestone, 1 ft. 2 in. thick, has been met with at a depth of only 23 ft. beneath the surface. Farther north, at a point 500 yds. south-east of the ruins of Dolphingston, limestone is said to have been reached in a bore at a depth of 150 ft.

C. T. C., C. B. C., E. M. A.

The Edge Coal Group.

This group, comprising all the beds between Limestone No. 3, or its supposed equivalent on the west side of the basin, and Limestone No. 4, includes many thick coal seams, and is the most important division of the Carboniferous Limestone series. Where most completely developed it is sometimes more than 1000 ft. thick and contains not less than twenty-six beds of coal above 1 ft. thick. This development occurs, however, only in the northern and central parts of the coal-field—in the neighbourhood of Duddingston, Niddrie, Gilmerton, Loanhead, Dryden and Dalkeith. At Gilmerton the total thickness of all the seams exceeding 23 in. in this group appears to be rather more than 80 ft.—about 14 ft. more than the total thickness of all the seams exceeding 23 in. in the Coal Measures proper in the neighbourhood of Joppa and Craighall. Along the southern and south-western outcrop the group is thinner, and many of the coals seem to have disappeared or are not of sufficient thickness to be workable. In the neighbourhood of Arniston (in Bore No. 4, Arniston Mains) the distance between the top thick coal, probably the Great Seam—the highest coal usually worked—and the Parrot seam at the base of the group, is only 309 ft., while at Niddrie the distance between the corresponding seams is more than 800 ft.

On the western side of the coal basin the seams strike from the coast near Portobello through Duddingston, Niddrie, Drum, Gilmerton, Loanhead and Dryden. At all these places they are locally known as "edge" coals, on account of their steeply inclined and sometimes vertical positions, and, though the corresponding seams in the eastern side of the basin—at Wallyford, Carberry, Cowden, Newtongrange and Gorebridge—are much more gently inclined, it is convenient to use the term Edge Coal group to include the whole of the strata in this division.* On the east side of the basin these beds are to a large extent separated from the East Lothian coal-field

* It should be stated that the lower seams of the Lower Coal Measures are also locally called "edge coals" in those places where they are highly inclined.

by inliers of the Lower Limestone group, which are exposed near the summit of the Roman Camp anticline just described.

Attempts to correlate the coal seams on either side of the basin have been made by Mr. Robert Martin * and by Mr. Robert Dron.† There can be little doubt that the Great Seam has been correctly identified on either side, and that the North Coal on the west represents the Parrot Seam on the south-east side, but the correlation of the intermediate seams is uncertain. C. T. C.

NIDDRIE, PORTOBELLO AND GILMERTON FIELDS.

Mining in this district has been carried down to greater depths than anywhere else in Scotland. Coal is being raised from the Great Seam at a depth of 2623 ft. vertically beneath the surface and this seam has been proved at a depth of 2756 ft.

In the Niddrie Collieries the dip is extremely irregular, ranging from 60° east to vertical, while occasionally the strata are inverted; ultimately, however, the seams flatten out toward the centre of the Mid-Lothian basin, which is reached in the Coal Measures at Olive Bank, Musselburgh.

To show the irregularity of dip, the varying angles observed in an incline in No. 10 Pit in the Stairhead Coal may be cited. At 1230 ft. below Ordnance Datum it is 56°. This decreases to 53° on the 1600 ft. level, but again increases to 71° at greater depths; after which the beds rapidly flatten out, as shown in the accompanying section (Fig. 17).

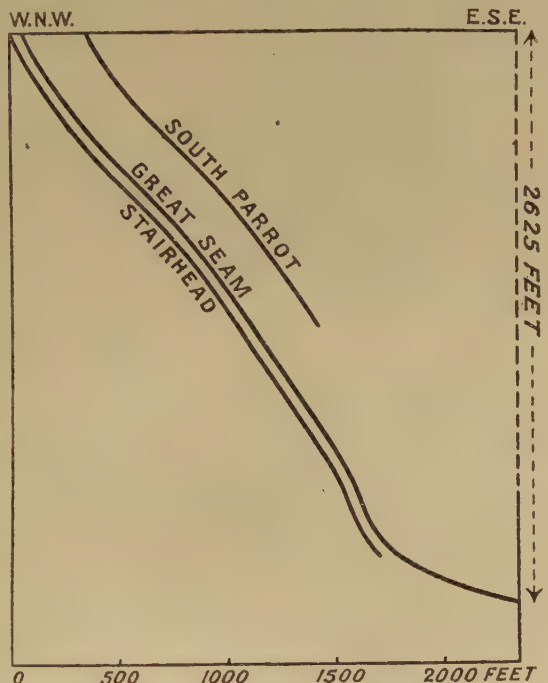

FIG. 17.—Diagram Section showing inclinations of the seams in No. 10 Pit, Niddrie Colliery.

In the northern portion of the workings the strata are interrupted by two basalt dykes.

On the shore at Joppa the strata are entirely obscured by the sand, but about a quarter of a mile inland some of the higher beds of the group are exposed in Joppa Quarry. The whole of the Edge Coals were proved in the old mining operations at Duddingston, and

* *Op. cit.*
† "The Coal-Fields of Scotland," 1902, p. 223.

the following general section gives the local names and thicknesses of the coals and of the intermediate strata:—

	Ft.	In.
Flex Coal	4	0
Intermediate strata	30	0
Laverock Coal	3	0
Intermediate strata	24	0
Great Seam Coal	8	0
Intermediate strata	36	0
Stairhead Coal	4	6
Intermediate strata	60	0
Gillespie Coal	4	6
Intermediate strata	142	0
Little Gillespie Coal	3	0
Intermediate strata	30	0
Black Chapel Coal	5	6
Intermediate strata	60	0
Stinkie Coal	3	0
Intermediate strata	30	0
Little Splint Coal	3	0
Intermediate strata	60	0
Big Splint Coal	4	0
Intermediate strata	60	0
Real Corbie or Stony Coal	5	0
Intermediate strata	150	0
Coal	5	0
Intermediate strata	78	0
Carleton Coal	5	6
Intermediate strata	54	0
Rough Coal	3	9
Intermediate strata	30	0
Blue Coal	3	9
Total thickness	909	6

At Niddrie the thickness between the Great Seam and the Index Limestone is about 130 ft.

The section on the west side of the now disused Joppa Quarries is as follows, in descending order:—

	Ft.	In.
Black papery shales	2	0
Coal	0	6
Dark fireclay	0	8
Sandy fireclay	1	6
Nodular fireclay	1	8
Grit, flaggy at bottom	5	6
Grey shale	3	6
Flags	1	0
Grey shales	2	3
Coal	1	0
Flags and grey shales	5	0
Coal, Stairhead (?)	2	4
Sandy fireclay	2	4
Nodular fireclay	6	0
Coal	3	0
Fireclay	0	6
Grit	1	0
Massive grit	8	0

The above beds are dipping about 61° to the east, but allowance for this has been made in estimating the thicknesses.

The following section is recorded from a crosscut (belonging to

the Niddrie Collieries) situated just south of Brunstane Burn—the same crosscut which furnished the section of the Lower Limestone group:—

Section of Part of the Edge Coal Group in the Niddrie Collieries.

	Ft.	In.
GILLESPIE COAL.		
Fakes	8	2
Sandstone	3	3
Fakes	4	11
Sandstone	16	4
Blaes	11	6
Sandstone	38	7
Blaes	13	11
Sandstone	7	5
Blaes	7	5
Sandstone	15	7
Blaes	4	11
LITTLE GILLESPIE COAL	2	0
Fireclay	1	8
Sandstone	6	7
Faky blaes	18	1
COAL	2	0
Blaes — BLACK CHAPEL OR CORBIE CRAIG	1	6
COAL	2	0
Fakes	16	10
Blaes	2	11
Sandstone	14	9
Blaes, soft	16	5
STINKIE COAL	2	8
Sandstone	9	10
Blaes	6	2
LITTLE SPLINT COAL	1	10
Sandstone	3	8
Fakes	12	4
Sandstone	5	9
Blaes	2	6
Sandstone	22	2
PEACOCKTAIL (BIG SPLINT) COAL	4	0
Fireclay	3	1
Sandstone	34	6
Blaes	4	11
Sandstone	9	10
Blaes	18	11
COAL	2	6
Blaes — REAL CORBIE OR STONY	1	5
COAL	1	5
Fakes	18	1
Sandstone	66	5
Blaes	8	2
Sandstone	40	2
FOUL COAL	2	0
Sandstone	8	2
Fakes	4	11
Sandstone	15	7
Fakes	8	2
Sandstone	1	8
Fireclay and blaes	6	2
Sandstone	28	8
Blaes with rib of clay	18	1
Sandstone	60	8
Blaes	15	7
Carry forward	666	9

	Ft.	In.
Brought forward ..	666	9
Carleton Coal	3	0
Blaes	9	10
Coal	1	8
Sandstone	13	11
Blaes	4	11
Coal	1	8
Fireclay	4	11
Coal	1	6
Blaes	27	0
Sandstone..	10	7
Blaes*	11	6
Sandstone..	12	4
Faky blaes	57	5
Limestone.		
	827	0

The thin coals beneath the Carleton were not named in this account of the crosscut, and the strata beneath the Carleton appear to be very variable, for Mr. Martin gives the following section from No. 15 Pit, Niddrie :—

Section in No. 15 *Pit, Niddrie.*

	Ft.	In.
Carleton Coal	4	10
Strata	20	0
Candle Coal	2	0
Strata	30	0
Blackband Ironstone	2	0
Strata	10	0
Blue Coal	1	10

It will be seen that 300 ft. of strata separate the Carleton from the next coal of good quality above it, namely, the Stony or Real Corbie. In this interval, a little farther south, we find the Corbie Craig of Gilmerton, which is the best-known coal in the south-western portion of the basin. At Niddrie, parrot is found in the Great Seam and the Stairhead—both in the upper portion of the series—and in the Candle Coal—in the lower portion—but in none of the intermediate seams. The parrot of the Great Seam is the best of those wrought at Niddrie, and Mr. R. W. Dron † has shown that it diminishes in thickness towards Joppa and Gilmerton. The section of this seam at Niddrie is as follows :‡—

	Ft.	In.
Coal, unworked .. .. 4 in. to	0	9
Cannel or Gas Coal .. .. 1 ft. 2 in. to	2	6
Ironstone .. .. 4 in. to	0	8
Pelt or Crow Coal .. .. 3 in. to	0	9
Coal .. .. 1 ft. 2 in. to	1	6
Daugh or Blae Holing .. .. .. 4 in. to	1	8
Bottom Coal, unworked .. .. .. 2 ft. 6 in. to	4	0

* A dolerite dyke crossed the section between this and the overlying bed.

† *Op. cit.* p. 225.

‡ R. Martin, "First Report of the Royal Commission on Coal Supplies," 1903, vol. i. p. 79.

A thin ironstone occurs with the Stairhead parrot also, and both the Great Seam ironstone and the Stairhead ironstone are wrought at the same time as the coal.

The section of the Stairhead seam at Niddrie is given below:*—

	Ft.	In.
Steam Coal	1	6
Stairhead Cannel	2	2
Blackband Ironstone	0	6
Blackband Ironstone (*inferior*)	0	4
Rough Coal (*steam*)	1	6

The only exposure of the group between Joppa Quarry and Drum is to the east of Niddrie Mill, in an old quarry where a coal is exposed, which, though only 18 in. thick, appears from its position and the associated rocks to represent the Peacocktail of Niddrie. A little to the south, in a crosscut from No. 13 Niddrie Pit, a shale containing *Lingula* was found. It lay about half-way between the Stinkie and the Black Chapel Coals, and seems, therefore, to be on a higher horizon than the shale, recorded by Dr. Traquair† as containing *Lingula* at Loanhead, which overlies the No. 1 Ironstone of that colliery. Dr. Traquair also refers to a band with *Lingula squamiformis*, which occurs probably about 10 ft. above the horizon of the North (Blue) Coal of Niddrie. Fish remains of the ordinary estuarine type, as Dr. Traquair points out, are associated with the *Lingula*, and it seems probable that this band represents the persistent seam of *Lingula* shale which overlies the Arniston Parrot in the south-eastern portion of the basin.

At Drum, and again near Gilmerton, in the interval between the Great Seam and the Index (No. 4) Limestone, a soft yellow grit was formerly dug out to supply sand for stable yards. Between these two places the outcrops have been shifted by a fault, the course of which is only partially known, which acts as an important water barrier between the Niddrie and Gilmerton mines.

The succession of the beds at Gilmerton is shown in the following section, the original of which was taken from an old document in the possession of Sir David Baird, but the names of the coals, except that of the top seam, are taken from Mr. T. A. Tweedie's Report on the Coal-field (1890). The strata above the Flex Coal are taken from an old plan by John Ainslie (1786):—

	Ft.	In.
Index Limestone.		
Intermediate strata	28	6
Baxlew Coal	2	0
Intermediate strata	36	0
Flex Coal	4	0
Intermediate strata	60	0
Rumbold Coal	2	0
Intermediate strata	6	0
Laverock Coal	3	0
Intermediate strata	36	0
Great Seam Coal	10	0
Intermediate strata	18	0

* R. W. Dron, *op. cit.* p. 227.

† "On the Distribution of Fossil Fish Remains in the Carboniferous Rocks of the Edinburgh District," *Trans. Roy. Soc. Edin.*, 1903, vol. xl. pt. iii. p. 694.

	Ft.	In.
Stairhead Coal	3	6
Intermediate strata	66	0
Gillespie Coal	3	6
Intermediate strata	60	0
Black Chapel Coal	7	0
Intermediate strata	9	0
Perpetual Coal	2	9
Intermediate strata	24	9
Kittlepurse Coal	2	2
Intermediate strata	120	0
Stinkie Coal	4	0
Intermediate strata	24	0
Rough Coal	4	9
Intermediate strata	114	0
Glass Coal	3	4
Intermediate strata	50	0
Parrot or Stony Coal	3	9
Intermediate strata	60	0
Corbie Craig Coal (with parting)	8	0
Intermediate strata	48	0
Peacocktail Coal	4	0
Intermediate strata	54	0
Carleton Coal	5	6
Intermediate strata	84	0
Blue Coal	7	0
Intermediate strata	90	0
LIMESTONE.		

It will be noticed that no coal under two feet thick is recorded in the above section, and that the total thickness of the coal specified is 80 ft. 3 in.

It is not certain that the Black Chapel Seam of Gilmerton is on exactly the same horizon as the coal with the same name at Niddrie. In addition to the Great Seam and the Stairhead, three coals occupying a central position in the Gilmerton section contain parrot, namely the Kittlepurse, the Stony and the Corbie Craig. From the imperfect record of the section which now remains it is impossible to say whether the Loanhead ironstones are represented at Gilmerton or not. Between Niddrie and Loanhead the Stairhead is distinguished by the possession of a very good roof, so that it is specially adapted to form positions for permanent inclines. It acquired its name in fact from being often used for stairways before the days of mechanical haulage. W. G., E. B. B.

LOANHEAD AND MAURICEWOOD FIELDS.

The dip workings and the cross-cut mines in the Loanhead and Burghlee Collieries show that the Edge Coals and the Upper Limestone group dip to the south-east at high angles. At Burghlee Pit the Great Seam has been worked to a depth of 1578 ft. (vertical) or 1860 ft. along the incline, with an average inclination of 58° to the south-east. At the bottom of the mine the dip decreases to 7° or 5° and continues at this low inclination as far as the coal has been worked, for a distance of 1200 ft. to the east. This change from the high angle on the west side of the basin to the comparatively flat angles of the central area, though sharp, is not accompanied by any line of dislocation.

At Roslyn Colliery and Glencorse Burn the Edge Coals dip to the south-east. The underground workings at Greenlaw, together with the sections in the Glencorse Burn at Auchindinny and in the river Esk half a mile above the Roslin Powder Mills, show that the Edge Coals, still dipping to south-east, flatten out for a short distance, and then rise gently to the south-east (see Fig. 18). This change of inclination takes place nearer the surface than at Loanhead, which is quite in accordance with the fact that the Mid-Lothian basin becomes shallower towards the south.

The accompanying section (Fig. 18) has been drawn from Mauricewood House to Bore No. 28, near Loanstone, to illustrate the folding of the strata in that part of the field. The old ironstone workings of the Mauricewood pit* show that the Edge Coals dip down sharply to south-east for some little distance below sea-level, and then suddenly become flat. After slight undulations for a considerable distance near Eastfield the dip proved underground changes to the north-west, and the crest of an anticlinal fold is pierced by Bore No. 29 (see Fig. 18), on the south-east side of which the beds rise again towards the south-east, so that the Castlecary Limestone crops out at Loanstone.

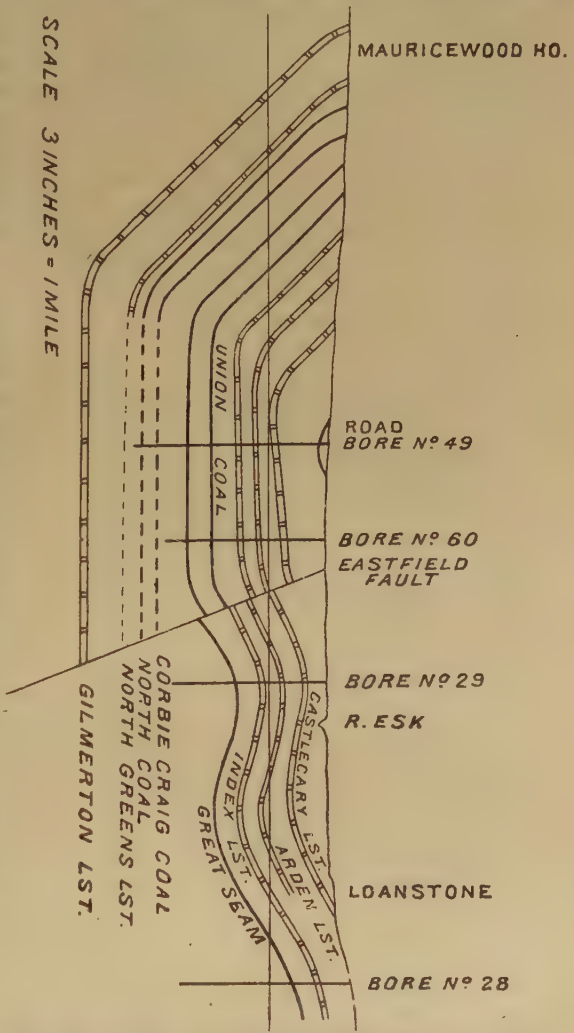

FIG. 18.—Section from Mauricewood House to Loanstone, showing folding of the Carboniferous Limestone Series.

From Mauricewood to Cuiken Burn the ground is faulted and

* In the Mauricewood pit the lower coals near the surface become nearly vertical and this is the beginning of the reversal of the strata in the vicinity of the Pentland fault seen in the Nine Mile Burn.

disturbed, and the crops, as laid down on the map, are chiefly calculated and protracted from boring information.

Several dislocations were supposed to traverse that portion of the Edge Coals which lies to the south-west of Laverock Hall, Gilmerton, and as a large east and west fault has been proved in the Burdiehouse Limestone Mine (60 fms. downthrow to the north) a curved line has been drawn from near Long Loan by Wester Melville to connect it with the known position of the Sheriffhall fault to the east.

As regards the tract between this fault and the Edgefield dislocation, very little mining information is available, but the coals are believed to be there inclined at a high angle to the south-east, and in some cases may be vertical.

The position of the Flex Coal has been got in a pit 26 fms. in depth, situated 500 yds. to the west of Wester Melville. From this point to the proved crop of the Fells Shale the strata would require to be nearly vertical in order to allow all the beds to crop out.

The strata in the cross-cut mines in the Burghlee and Loanhead pits have now been measured, and the details are given in the subjoined table:—

Section of Edge Coals and Intermediate Strata at Loanhead.

	Ft.	In.	Ft.	In.
LIMESTONE, INDEX.				
Strata			102	0
COAL, FLEX	5	0		
Strata			72	0
No. 3 IRONSTONE or RUMBLES PARROT	4	6		
Strata			12	0
COAL, GREAT SEAM	8	0		
Strata			34	6
,, STAIRHEAD	3	4		
Strata			22	9
No. 2 IRONSTONE or CHARLIES COAL	2	7½		
Strata			24	0
COAL, MOFFATS	2	0		
Strata			9	2
,, GILLESPIE	3	4		
Strata			49	1
,, BLACKCHAPEL	5	2		
Strata			4	0
,, PERPETUAL or CALPATIE	2	2		
Strata			61	4
,, KITTLEPURSE	3	0		
Strata			33	6
,, STINKIE or PEACOCK	3	10		
Strata			51	6
,, ROUGH	3	0		
Strata			40	7
,, GLASS	3	6		
Strata			16	5
No. 1 IRONSTONE	3	6		
Strata			7	6
COAL, BROWNS	1	7		
Strata			100	11
,, ROUGH	0	7		
Strata			14	8
,, STONY or PARROT AND ROUGH	5	3½		
Strata			10	0
Carry forward	60	5	665	11

	Ft.	In.	Ft.	In.
Brought forward ..	60	5	665	11
Coal, Hopes .. .. 1 ft. 8 in. to	2	0		
Strata			14	7
„ Beattie .. .. 1 ft. 10 in. to	3	11		
Strata			20	0
„ Corbie Craig or Corbie Rough	4	11		
„ „ Splint	4	2		
Strata			107	10
„ Andrews or Little Splint .. 2 ft. 10 in. to	5	10		
Strata			48	8
„ South or Carleton .. .. 4 ft. 2 in. to	5	8		
Strata			24	0
„ Little	1	4		
Strata			17	1
„ Little Splinty or Cannel Fir	1	2		
Strata			1	9
„ North or Blue .. .. 3 ft. to	4	6		
Strata			15	0
Limestone.				
	93	11	914	10

The lowest seam in the above vertical section—the North Coal—is separated, in the Bilston Burn, by 15 ft. of yellow sandstone and blaes from the 20-in. limestone which there forms the top of the Lower Limestone group. This seam is the equivalent of the Blue Coal of Gilmerton. In the latter field it is 7 ft. thick; at the Edgefield fault, 4 ft. 6 in.; and at Loanhead, 4 ft.; while at the Dryden March it is reduced to 2 ft. 11 in. It is a rough coal mixed with splint of superior quality. The upper portion is sold as household coal. The sections at Dryden March and Loanhead are given below:—

At Dryden March.

	Ft.	In.
Roof, blaes.		
Splint Coal	2	0
Free „	0	11
	2	11
Pavement, sandstone	0	11

At Loanhead.

	Ft.	In.
Roof, blaes.		
Free Coal	0	6
Splint „	0	9
Free „	0	4
Splint „	0	9
Soft Free Coal	1	6
Daugh	0	2
	4	0
Pavement, sandstone	0	11

The Little Splinty or Cannel Fir Coal, 1 ft. 2 in. thick, lies immediately above the North Coal, being separated from it by thin bands ranging from 1 ft. 9 in. to 2 ft. 3 in. in thickness. It is a hard splint coal of very superior quality, but has never been wrought. The roof is composed of bands mixed with blaes, and the pavement is a soft fireclay. The Little Coal, about 1 ft. 4 in. thick, is a soft

rough coal mixed with splint of good quality, which has never been worked.

The South Coal varies in thickness, becoming thinner towards the south-west. It is a hard, rough, second-class house coal, the upper portion being splinty, and the lower very soft. It is the equivalent of the Carlton Coal in the Gilmerton field, and shows the following sections at Dryden and Loanhead:—

		Ft.	In.
At Dryden.	Roof, blaes.		
	Inferior Coal ..	1	0
	Hard Fireclay	0	4
	Splint Coal ..	2	10
		4	2
	Pavement, blaes.		

		Ft.	In.
At Loanhead.	Roof, blaes.		
	Inferior Coal	1	0
	Parting ..	0	2
	Splinty Coal	1	7
	Free Coal ..	2	11
		5	8
	Pavement, fakes.		

The Andrews or Little Splint Coal varies from 2 ft. 10 in. to 5 ft. 10 in. according to the thickness of the stone interleaved with it. The lower portion is a soft rough coal, and the top coal is harder but full of iron pyrites. In working, it breaks up into dross as the holing has to be done in the bottom bed. It has only been wrought to a limited extent for steam purposes, and has the following section:—

	Ft.	In.
Roof, blaes.		
Soft Coal	2	6
Black stone	1	8
Coal	1	8
	5	10
Pavement, fakes.		

The Corbie Splint and Corbie Craig Coals display the following sequence at Loanhead:—

		Ft.	In.
	Roof, fakes with ribs of blaes.		
Corbie Craig, 4 ft. 11 in.	Sclutty Coal, inferior	1	2
	Free ,, ...	1	5
	Splint ,, ...	0	3
	Free ,, ...	1	8
	Sclutty ,, inferior	0	5
Corbie Splint, 4 ft. 2 in.	Splinty ,, ...	1	6
	Free ,, ...	1	10
	Sclutty ,, inferior	0	10
		9	1
	Pavement, soft fireclay.		

The lower seam or Corbie Splint is a superior splint coal, varying in thickness; the upper seam or Corbie Craig is a firm rough coal of good quality. Both become thinner in a south-west direction towards Dryden, the Corbie Splint being reduced to 2 ft. 9 in. at Dryden, while the Corbie Craig, which has a thickness of 4 ft. 11 in. at Loanhead, diminishes to 4 ft. at Dryden. At Loanhead the two coals come together, but in some portions of this field they are separated by 10 to 18 ft. of strata. The pavement of the Corbie Splint consists in places of bands and fireclay and in others of very coarse sandstone.

The strata separating the Beattie Coal from the Corbie Craig are

thicker at Loanhead than towards Dryden. At Dryden March, as shown in the following section, they consist merely of 30 in. of blaes, which, together with the Beattie Coal, 2 ft. 7 in. thick, is left as a roof to the Corbie Craig:—

			Ft.	In.
Section at Dryden March.		Beattie Coal	2	7
		Blaes	2	6
		Corbie Craig Coal	4	0
		Fireclay	0	9
		Rock	6	0
	Corbie Splint, 2 ft. 9 in.	Splint Coal	1	6
		Free „	0	10
		Sclutty „ inferior	0	5
		Fireclay	1	1

A reduction of thickness towards the south-west has also been observed in the Beattie Coal. At Loanhead the top portion of this seam is a firm rough coal of good quality; the remainder rather soft; both being sold as household coal. The bottom sclutty portion varies from 9 to 15 in. in the mine, and, when the stones are removed, is used for steam purposes.

The Hopes Coal is a variable rough seam and has only been partially wrought. It has the following sections:—

	Ft.	In.		Ft.	In.
Roof, sandstone and blaes.					
Wild Parrot Coal	0	4	and	0	10
Coal	1	4	„	1	2
	1	8		2	0

The Stony or Parrot and Rough Coal is separated from the Hopes Seam by strata varying in thickness from 10 to 31 ft. The Parrot on top is poor in quality and not always present. The seam, which is all exhausted down to the Mavisbank day-level, displays the following sections:—

	Ft.	In.
Roof, black blaes.		
Parrot Coal	1	2
Fireclay	0	1½
Coal	1	2
Stone	0	5
Coal	2	5
	5	3½
Pavement, blaes.		

	Ft.	In.
Roof, blaes.		
Parrot Coal	0	4
Wild Parrot Coal	0	4
Ball Ironstone	0	4
Coal	1	2
Sandstone	0	1½
Coal	1	1
Sandstone	0	1½
Coal	1	0
	4	6
Pavement, sandstone.		

The blaes roof is very brittle and the Ironstone and Parrot are left to support it. The seam below is a rather soft rough coal of fair quality, which is sold for household purposes.

The Rough Coal above the Stony Seam is a coarse rough coal which has not been wrought.

The Browns Coal varies in thickness from 1 ft. 7 in. to 2 ft. 6 in., and is believed to be entire throughout this coal-field.

The No. 1 Ironstone,—an important fossiliferous horizon,—furnishes the sections given below:—

Dryden March.

	Ft.	In.
Roof, blaes.		
Clayband Ironstone	0	5
Wild Parrot Coal	1	0
B. B. Ironstone	0	8½
B. B. „	0	5
Daugh Coal	0	3
Pavement, hard blaes.		
	2	9½

Loanhead.

	Ft.	In.
Roof, blaes.		
Ironstone	0	1
Clayband Ironstone	0	4
Wild Parrot Coal	1	0
„ „ with Ironstone	1	3
Pavement, fireclay.		
	2	8

Loanhead.

	Ft.	In.
Roof, blaes.		
Top Ironstone	0	8
Light band (parrot and ironstone of no value)	0	3
Wild Parrot Coal, top band	0	6
„ „ „ bottom band	0	9
B. B. Ironstone	0	9
Bottom B. B. Ironstone	0	8
Pavement, sandy fakes.		
	3	7

It is overlain by a *Lingula* shale, and both have yielded fish remains which have been determined by Dr. Traquair,* but the zone is not so prolific as the Rumbles Ironstone to be described presently.

The Glass Coal is a hard rough coal, ribbed with splint, is of a good quality and shows the following sequence:—

	Ft.	In.
Roof, sandstone and blaes.		
Free Coal	2	4
Daugh Coal	0	1
Free Coal	1	1
Pavement, faky blaes.		
	3	6

The Rough Coal above the Glass varies in thickness from 1 ft. 9 in. to 3 ft., and is a hard rough coal with a bad roof and pavement. It is believed to be unwrought throughout this coal-field.

The roof coal of the Stinkie or Peacock Seam is a fine splint. The under coal varies from 3 ft. to 4 ft. 2 in. in thickness and is a rough free coal full of iron pyrites—suitable only for steam purposes. The sections at Dryden and Loanhead are given below:—

Dryden.

	Ft.	In.
Roof, blaes.		
Coal	0	1
Splint Coal	1	0
Rough „	2	6
Fireclay	0	1
Pavement, hard blaes.		
	3	8

Loanhead.

	Ft.	In.
Roof, blaes.		
Fine Splint Coal	0	10
Coal	3	0
Pavement, fireclay.		
	3	10

* *Trans. Roy. Soc. Edin.*, 1903, vol. xl. plate iii. p. 695.

The Kittlepurse Coal is ribbed with splint of a superior quality, is sold as a good household coal, and has the following section :—

Roof, blaes.	Ft.	In.
Wild Parrot Coal	1	2
Coal	1	6
	2	8

Pavement, fireclay.

The Perpetual or Calpatie Coal is of variable thickness, sometimes amounting to 2 ft. 2 in. It is a firm rough coal of inferior quality, and has been wrought only to a limited extent in this field. In part of the Burghlee workings it shows the sequence given below :—

Roof, blaes.	Ft.	In.
Ironstone	0	3
Blaes..	0	6
Coal	0	5½
	1	2½

Pavement, fireclay.

The Blackchapel Seam is a thick, soft, free coal of poor quality, with ribs of stone and iron pyrites, suitable only for steam purposes. It shows the following composition :—

Roof, sandstone.	Ft.	In.
Coal	3	5½
Fireclay	0	5
Coal	0	4
Parting	0	0½
Coal	0	11
	5	2

Pavement, fireclay.

The Gillespie Coal, occasionally 5 ft. thick, is a soft rough coal of good or medium quality and used chiefly for steam purposes. It furnishes the sequence given below :—

Roof, sandstone.	Ft.	In.
Shale	0	10
Coal	3	0
	3	10

Pavement, fireclay.

The Moffats Coal, which varies in thickness from 9 in. up to 2 ft., is a good rich smithy coal with a soft blaes roof and fireclay pavement, but has not been wrought.

Charlies Coal or No. 2 Ironstone displays the following sections :—

Roof, black blaes.	Ft.	In.
Ironstone	0	1
Black blaes	0	10
Gas Coal	0	10
Ironstone	0	8
	2	5

Pavement, coaly sclit.

	Ft.	In.
Roof, sandstone.		
Wild Parrot Coal	0	8
„ „ „	0	10
Ironstone Band	0	4½
Wild Parrot mixed with Rough Coal and occasional Ironstone 2 in. thick	0	9
	2	7½

The Parrot or Gas Coal in this seam was tried in 1849 at the Edinburgh Gas Works and was reported to be of inferior quality, probably because the coal had not been properly cleaned before it was sent to the Gas Works. The ironstone is of good quality.

The Stairhead Coal is a rough coal of second-class quality with the following sequence:—

	Ft.	In.
Roof, sandstone.		
Coal	1	4
„ Duff	0	4
„	1	8
	3	4

Pavement, sandstone.

The Great Seam yields coals of good quality, the upper or splinty portion forming an excellent household coal. Three sections are given below:—

	Ft.	In.		
Roof, black blaes.				
Coal, Craw	0	8		
Blaes	0	9		
Coal, Splinty	1	3		
„ Free	0	9½		
„ Parrot	0	2½	Ft.	In.
„ Free	2	0	8	0½
Fireclay	0	3		
Coal, Free	1	11½		
Fireclay	0	1		
Coal, Ground	1	6		
Fireclay	0	3		
	9	8½		

	Ft.	In.
Roof.		
Fireclay ..	0	5
Coal	4	10
Fireclay ..	0	4
Coal, Bottom	1	9
Fireclay ..	1	7
	8	11

	Ft.	In.
Banded roof.		
Coal, Ribbed Splint	5	0
Coal, Rough ..	1	6
	6	6

No. 3 Ironstone or Rumbles Parrot or Ironstone and Gas Coal is 12 ft. above the Great Seam at Loanhead, but 18 ft. above that horizon at Dryden, where it was chiefly wrought for its excellent gas

coal, which thins out to 2 in. to the east. At Dryden its composition is as follows:—

	Ft.	In.
Roof, blaes.		
Coal, Wild Parrot	1	6
Ironstone	0	9
Coal, Gas	1	8
Ironstone	0	7
	4	6

At Loanhead the Rumbles Seam is a rich soft coal. The wild parrot in the centre varies from 4 to 10 in. in thickness and was sold with the coal, for which there was an excellent local demand. The sequence in one part of Loanhead is given below:—

	Ft.	In.
Roof, blaes.		
Soft Coal	1	4
Coal, Wild Parrot	0	7
„ Soft	1	1
	3	0
Pavement, rock.		

On the west side of Loanhead the seam contains from 5½ to 8 in. of excellent parrot and also 11 in. of free coal. As the holing is made in the 1 ft. 3 in. of coal, and the mined coal is shot down the steep spouts to the workings below, a large portion of the seam is reduced to small coal and dross. There the sequence is as follows:—

	Ft.	In.
Roof, blaes.		
Coal, Wild Parrot	1	0
Ironstone	0	2
Coal, Parrot	0	8½
„ Free	0	11
Coal	1	3
Coal, Free	0	4
	4	4½
Pavement, sandstone.		

The No. 3 Ironstone, separated by 12 ft. of strata from the Great Seam below, is especially noteworthy as the most productive fish bearing bed in the Lothians. Dr. Traquair,* who calls this band the Borough Lee or Loanhead Ironstone No. 2, has recorded 35 species from this locality.

The Flex Seam is a good rough coal, and when separated from the Duff is sold as a good household coal similar in quality to the Great Seam. The following is a representative section:—

	Ft.	In.
Roof, sandstone.		
Coal, Duff	0	8
„ Rough	3	4
	4	0
Pavement, soft fireclay.		

All the seams in the Loanhead field attain their maximum thickness and quality in the vicinity of the Edgefield faults. To

* *Trans. Roy. Soc. Edin.*, 1903, vol. xl. p. 695.

the south-west they become thinner and of inferior quality, with the exception of the No. 3 Ironstone or Rumbles Parrot.

Section of Edge Coals and Intermediate Strata at Roslin.

	Ft.	In.	Ft.	In.
Coal, Stairhead	1	7		
Strata			10	6
„ Charlies	1	6		
Strata			22	8
Ironstone No. 2	1	2		
Strata			3	1
Coal, Moffats	0	10		
Strata			19	0
„ Gillespie	2	6		
Strata			48	10
„ Blackchapel	2	6		
Strata			83	6
„ Kittlepurse	2	0		
Strata			47	9
„ Peacock	3	9		
Strata			73	8
„ Glass	2	6		
Strata			49	2
„ Browns	2	6		
Strata			59	5
„ Stony	3	0		
Strata			49	2
„ Beattie	1	6		
„ Corbie Craig	4	6		
Strata			1	0
„ Corbie Splint	3	4		
	33	2	467	9
			=500	11

The details in the above section are taken partly from a shaft, 80 fms. deep, sunk at the new colliery at Roslin to about 5 fms. below the Peacock Coal. The rest of the section has been obtained from two stone mines, one driven towards the Great Seam and the other in the direction of the North Coal.

In the area between Loanhead and Penicuik the thickest coal is that formed by the practical coalescence of the Beattie, Corbie Craig and Corbie Splint Coals. The section of these three seams in Roslin North Mine is as follows:—

	Ft.	In.
Ironstone	0	2
Blae	0	9
Coal, Beattie	1	6
„ Corbie Craig	4	6
Blae	1	0
Coal, Splint	1	6
„ Rough	1	10
	11	3

This Roslin Pit is connected with the Burghlee and Loanhead workings by a continuous level road in the Peacock Seam, which also extends as far as the Edgefield fault, a distance of two miles.

Between Loanhead and Roslin the strata between the top of the

Stairhead and the base of the Corbie Splint Coal diminish in thickness 2½ per cent., and the coals and ironstones, 44 per cent., as shown by the following tables:—

	Loanhead Section.		*Roslin Section.*	
	Ft.	In.	Ft.	In.
Coals, total thickness	57	11	32	4
Strata	480	0	467	9
	537	11	500	1

Between Roslin Pit and Gowklie Moss, a fault shifts the strata on the south-west side some distance to the north-west, from which dislocation to Greenlaw no mining operations have been carried on since that area was first mapped by the Geological Survey. In the Mauricewood Colliery the following seams are worked, namely the Johnston, Union, Stairhead, Corbie Jewel and Corbie Splint, this field being separated from the Greenlaw workings by a fault with a downthrow to the south, amounting in places to 45 fms. but diminishing at the Mains to 25 fms.:—

Section of Edge Coals and Intermediate Strata at Mauricewood.

	Ft.	In.	Ft.	In.
Coal, Johnstone	4	0		
Strata			42	0
„ Waverley	2	6		
Strata			15	0
„ Union (Flex Coal of Loanhead)	4	0		
Strata			7	2
„	1	4		
Strata			41	3
Ironstone	0	4		
Strata			12	9
B.B. Ironstone	1	0		
Strata			1	8
Coal, Great Seam	8	4		
Strata			17	0
„	1	7		
Strata			1	0
„ Stairhead	3	1		
Strata			4	10
„	2	4		
Strata			24	5
„	1	6		
Strata			15	0
„ Gillespie	2	6		
Strata			36	1
„ Blackchapel	1	9		
Strata			163	6
„	2	2		
Strata			17	10
„	1	1		
Strata			17	3
„ Corbie Jewel	4	2		
Strata			10	3
„ Corbie Splint	2	6		
Strata			68	10
„	1	6		
Strata			15	11
Carry forward ..	45	8	511	9

	Ft.	In.	Ft.	In.
Brought forward ..	45	8	511	9
Coal, South	2	4		
Strata			21	5
„ North	2	4		
Strata				
Limestone, Bilston Burn				
	50	4	533	2

The above section shows that the thinning of the coals and intermediate strata in a south-west direction already noticed between Loanhead and Roslin continues even in a greater degree towards Mauricewood. A comparison of the strata from the top of the Flex Coal to the base of the North Coal at Loanhead and Mauricewood proves that in the interval of three miles between these places the thickness of the strata exclusive of coals and ironstones has diminished 40 per cent. and the thickness of coals and ironstones combined, 53 per. cent., as shown in the following table:—

	Loanhead Section.		*Mauricewood Section.*	
	Ft.	In.	Ft.	In.
Coals and Ironstones, total thickness ..	93	5	43	10
Intermediate strata	797	10	476	2
	891	3	520	0

A careful analysis of the details of these two sections indicates that the strata, comprising 150 ft. of coarse sandstone and 9 ft. 4 in. of fireclay that lie between the Blackchapel and the next lowest coal shown in the Mauricewood section, must be the equivalents of the coal seams and associated strata, which, in the Loanhead section, come between the Blackchapel and the Stony Coals. Among these seams are the Kittlepurse, Peacock and Rough Coals. It is evident, therefore, that very different conditions of deposition must have prevailed in the Mauricewood area while these well-known coals were in process of formation between Loanhead and Roslin.

J. S. G. W.

PENICUIK FIELD.

AREA SOUTH OF PENICUIK.

The Edge Coals are not at present wrought anywhere within the limits of this Map to the south of Penicuik, but their position has been proved by a number of bores put down in different parts of the area to the south and south-west of Penicuik. The details of many of these bores have been kindly placed at our service by Mr. Gemmell, Mining Engineer.

The highest of these coals, the Flex, which in this part of the basin lies about 20 ft. below the Index Limestone, crops out in the small burn 500 yds. north-east of Penicuik House. It appears again, together with two other coals, probably the Rumbles and Great

Seam, in the steep bank on the north side of the Esk. The seam 3 ft. thick, seen in the old quarry west of the pond, dipping south-east at 30° beneath a thick sandstone, is probably the former coal. A bore put down close to the saw mill gives a good section of these coals. The beds are dipping south at 60°, and owing to the high angle the thickness of the seams given in the bore journal, is exaggerated. The first coal got in the bore (the Flex) is in two beds, the upper 2 ft., the lower 3 ft. 3 in. (true thickness). The second seam —the Rumbles—is also split by an 8-in. fireclay into two beds, 1 ft. 10 in. and 7 to 12 in. respectively, in true thickness. The Great Seam, 29 fms. from the surface, is in two beds, 17 to 20 in. and 6 to 8 in., separated by 19 to 30 in. of stone.

Between this point and the outcrop of the Index Limestone at Cornton, the beds are thrown into a series of gentle folds, and the thin coals of the Upper Limestone group seen in the Cornton Burn below the bridge at Cornton are lying in a series of shallow basins. It has not been found possible to identify or trace the outcrops of the two seams seen at intervals in this section, but it is probable that the Wood and South Parrot, both of the Upper Limestone group, may be represented.

The Flex and Rumbles Coals appear in the Cornton Burn 100 yds. above Cornton, and their outcrops follow the course of the stream for some distance. Where they first cross the burn the beds are vertical, and, a short distance farther up, the dip is slightly inverted towards the north-west.

The lower coals can be seen crossing the burn farther to the westward, where they have been identified successively as the Blackchapel, 16 in.; the Glass, 2 ft.; the Beattie, 10 in.; the Corbie Craig; and the North and South. The position of some of these coals in the ground between the Cornton Burn and the Esk, has been approximately fixed from their occurrence in the section of the Talla Water tunnel.*

The entire series of the Edge Coals, from the Flex to the North and South, are found at the old Brunston Colliery, on the north side of the Esk, which was worked for many years, up till about the middle of the last century, by a day-level driven from the river bank. The Flex is here a soft dirty coal, 22 in. thick. The Rumbles averages 3½ ft., and a small area of it was worked for steam coal. The Great Seam is not more than a foot in thickness and was not found to be workable, but other seams lying beneath it were wrought to some extent. The first of these is the Stony Coal, of poor quality, about 3 ft. in thickness, divided into two beds by 20 in. of stone. The next seam is the Corbie Craig, the best coal of this part of the area, which also occurs in two beds separated by 12 to 20 in. of fireclay. The top bed is a rough coal averaging 2 ft.; the lower gives 14 to 18 in. of good splint coal.

The lowest coals, the North and South, were here regarded as forming a single seam, composed of a splint coal of 13 in., a hard "kingle," 2 ft. 10 in. and a 20-in. coal below. The seam is hardly workable, but a small part of it has been wrought out.

The following section gives the details of the succession and

* Information kindly supplied by Messrs. Leslie & Reid, Engineers to the Edinburgh and District Water Trust.

thickness of the coals and intervening strata at the Brunston Colliery:—

*Section of the Edge Coals at Brunston Colliery.**

	Ft.	In.
LIMESTONE (No. 4)	4	0
Sandstone	16	0
FLEX COAL	2	10
White fireclay	13	2
RUMBOLDS (or RUMBLES) COAL	4	11
Sandstone and fireclay	2	3
LAVEROCK COAL	0	10
Sandstone	33	11
COAL	0	11
Sandstone	24	8
COAL—Great Seam	1	0
Fireclay and ironstone balls	5	3
STAIRHEAD COAL	1	11
Fireclay and ironstone balls	3	3
GILLESPIE COAL	1	8
Indurated clay	8	7
COAL, mixed with stone	0	9
Sandstone	22	6
Fireclay	1	1
Sandstone	74	3
Shale (blaes)	12	10
SPLINT COAL	1	0
Shale (blaes)	4	0
GLASS COAL	2	0
Indurated clay	2	2
STONY COAL	1	3
Coarse grey sandstone	18	0
HOPES COAL	0	8
Fireclay with ironstone balls	6	0
BEATTIE COAL	1	11
Sandstone and shale	30	0
Fine white sandstone	34	6
COAL	3	0
Fireclay } CORBIE CRAIG COAL	1	3
COAL	2	9
	345	1

A comparison of this section with that of Loanhead, 7 miles to the north-east, will show how greatly the beds have diminished, the total thickness of coal at Loanhead being over 80 ft., whereas at Brunston the same seams only amount to 27 ft. 5 in. Again at Mauricewood, 3 miles farther to the north, the thicknesses of the Great Seam and Gillespie Coals are respectively 8 ft. 4 in. and 3 ft. 1 in., while the same seams at Brunston measure 1½ to 1 ft. and 1 ft. 8 in. A similar thinning to the south is shown by the North Greens Coal (Lower Limestone group), which diminishes from 2 ft. in the Nine Mile Burn to a few inches or nothing at the south end of the basin.

A large fault, 50 fms. wide and filled with broken rock, runs through the Brunston Colliery. Its direction is north-west and south-east at right angles to the strike of the strata, and the down-throw is to the north-east. It is not improbable that this may be

* Communicated to Mr. Howell by Mr. J. Lawson, late manager of the Colliery.

two parallel faults, the rock being broken up between them. Two other faults interrupt the coals between Brunston and the Nine Mile Burn, both throwing the strata down on the north-east side.*

The Rumbles can be traced along the steep bank beneath the sandstone quarries south of Brunston Colliery, and is seen again, together with the Flex, in the face of the large quarry at Marfield, where an excellent freestone is wrought at the present time. The section now exposed in the Marfield Quarry is as follows :—

		Ft.	In.
	Sandstone.		
	Blaes	6	0
	Coal (Flex), soft dirty	1	5
	Blaes	6	0
Rumbles.	Coal	3	0
	„ Splint	0	10
	Blaes	1	6
	Fireclay	0	4
	Coal	0	4
	Shales	4	0
	Thick yellow sandstone	40	0 seen.

Three coals, identified by Mr. Howell as the Beattie, Corbie Craig, and North and South, are seen in the Nine Mile Burn dipping to the S.S.E. at 20° to 30°. Lower down, the burn is flowing over the thick yellow sandstone which underlies the Great Seam and Gillespie Coals. The Great Seam and higher coals cross the Esk at Marfield, and the low angle of dip allows of their appearance on the eastern bank, where the Great Seam is seen a few feet above the level of the river. It is here 18 in. in thickness, and rests upon fireclay and dark shales with ironstone nodules, beneath which is a thin seven-inch coal which may be the Stairhead. Above are dark shales and a thick sandstone. The outcrop of this seam is apparently cut off to the north by the fault which crosses the river in the hollow below the Marfield Quarry. On the same side of the river, a little farther to the north, the Flex and Rumbles Coals crop out beneath the steep escarpment formed by the 20-ft. sandstone that underlies the Index Limestone on the top of the bank.

Old air-shafts and shallow pits indicate where the Corbie Craig Coal has formerly been worked all through the estate of Newhall, and its outcrop crosses the North Esk near the lower bridge, immediately under Newhall House.

The Edge Coals underlie the Roslin Sandstone outlier on Auchencorth Moss, and the lower seams have been proved in several bores along the eastern edge of the basin between Howgate and Leadburn Junction (Sheet 24). At a point 420 yds. north-west of Venture Fair, the Corbie Craig Seam was found at 19 fms., the coal being 4 ft. 2 in. in thickness, divided into two beds by 15 in. of fireclay. In the other bores the same coal varies from 2 ft. to 3 ft. 3 in. The Beattie and Corbie Craig Seams crop out above the Peebles railway line between Venture Fair and Rose View, and were formerly wrought near Mosshouses by means of a day-level from the Lead Burn. The beds here dip W.N.W. at 30°; but the coal is now only visible at one point, in a sandstone quarry at Venture Fair. L. W. H.

* Much of the two preceding paragraphs is taken from Mr. Howell's original description. "Geology of Edinburgh" (1861), pp. 90, 91.

TEMPLE FIELD.

The examination of the natural sections taken in conjunction with the data obtained from the numerous bores put down by the Arniston Coal Company has made it possible to construct a generalised section of the beds which come above the thin limestone at the top of the Lower Limestone group. Near the bottom of the section a coal with a parrot band probably represents the Parrot Coal of the Arniston Colliery. It is seen in the South Esk above Temple and also in the bend of the stream below the junction with the Redside Burn, and has been struck in several of the bores of the Arniston Coal Company. The Coal 4 ft. thick near the top of the section at Temple is supposed to be the Kailblades Seam. Higher than any of the strata in the foregoing section are some of the beds with thin coals seen in the little burn running down from Redside, and near the south-westerly continuation of the Vogrie fault. The mapping of the ground south of Carrington and Redside has shown that this fault crosses the South Esk a short way below the junction with the Redside Burn, and is continued in a westerly direction through Redside and Fatlips, thus truncating the basin of the Coal Measures and Millstone Grit along its southern margin. Bores Nos. 1 to 5 and Bore No. 15, Arniston Mains, prove the continuation of this fault between Gorebridge and the South Esk, the Upper Limestones being faulted down against the Edge Coal group, and striking at the line of junction.

Near Temple, and for several miles farther west, some of the higher beds of the Edge Coal group and the Upper Limestone division have been probably cut out by the same fault, and the thickness of the Edge Coal group preserved between Yorkston and Redside perhaps does not exceed 200 ft. Owing to their gentle northerly dip the strata, however, cover a wide area. Bores Nos. 3 and 4, Arniston Mains, put down by the Arniston Coal Company, in the neighbourhood of Bells Mains, farther to the east near Fushiebridge, found the Parrot Coal at depths of 361 and 400 ft. The former bore was continued to the limestone, which it reached at 387 ft. At 78 ft. in Bore No. 3 a thick coal was met with, giving the following section:—

	Ft.	In.
Coal	3	0½
Fireclay	1	10
Coal	2	11

In Bore No. 4 the same coal was met at 90 ft., and gave the section shown below:—

	Ft.	In.
Coal	2	9½
Parrot	0	1
Rough Coal	0	11½

This coal probably represents the Great Seam. Other bores show that this coal is restricted to a small basin and probably bounded on one side by the Vogrie fault.

The underground workings of the Gore Pit show the continuation of the Roman Camp anticline as far south-west as Arniston Mains, the different level roads following one another in curves as the dip changes from west to south and S.S.E. Across the Vogrie

fault the southern continuation of the Roman Camp anticline is also shown by the Lower Limestones coming nearly to the surface near Arniston House, as is proved by Bore No. 16, which commences below the Parrot position and passes down into the limestones.

Three miles to the west, on the south side of the supposed continuation of the Vogrie fault near Fatlips, a fine-grained yellow sandstone with no clear dip is first seen, followed higher up the burn by a soft, rather coarse yellow sandstone, which dips W.N.W. These yellow sandstones, and also the sandstones, shales and thin coals seen farther south, in the old quarries near the reservoir for the Roslynlee Asylum, are supposed to belong to the Edge Coal group, but no fossils have been found to prove their Lower Carboniferous age. A seam of coal found in making the puddle trench of the reservoir is reported to be of good quality and thicker than those in the quarries. C. B. C.

THE GOREBRIDGE, NEWTONGRANGE AND COWDEN FIELDS.

In this district, on the east side of the coal basin, coal is now obtained from the following pits: New Gore, Emily (Arniston Colliery Co.), Lady Victoria (Newtongrange, Lothian Coal Co.), Bryans. Much of it is brought from great depths and considerable distances from the winding shafts. The forehead of the "Carrington Dook" in the Parrot seam in the Lady Victoria Pit is about 2200 ft. below the surface, at a locality about 500 yds. W.N.W. of Aikendean Farm. The beds near the forehead are undulating, but are probably on the eastern side of the centre of the basin.

In the Lady Victoria shaft the strata between Limestone No. 4 and the thin limestone (at the top of the Lower Limestone group) that underlies the Parrot seam are about 646 ft. thick,* and they include 15 coals of variable quality, which exceed 23 in. in thickness. The total thickness of coal and cannel, without counting partings of dirt, is about 70 ft. Most of the seams cannot, however, be worked with profit at great depths, and in the Victoria Pit the only seams being mined at the time of the revision by the Geological Survey were the Parrot and Bryans Splint. At Arniston the Great Seam and the Kailblades were also worked.

The following section shows the coals and intermediate strata as they were proved at the old Cowden Colliery, Dalkeith:—

	Ft.	In.
Index limestone (No. 4)		
Sandstone and shale (blaes)	29	4
Coal (Deception)	2	2
Sandstone	30	6
Coal (Cryne)	2	6
Sandstone	24	6
Shale	4	8
Sandstone	24	4
Coal (Mavis)	2	8
Sandstone	62	2
Coal (Great Seam)	8	0
Sandstone	7	0
Carry forward ..	197	10

* In these measurements a deduction has been made for dip.

	Ft.	In.
Brought forward ..	197	10
Coal (Diamond)	2	7
Sandstone and shale	15	2
Coarse blackband ironstone	0	5
Coal	1	10
Shale with bands	14	0
Coal (Siller Willie)	6	0
Sandstone	8	0
Coal	0	6
Sandstone bands..	6	6
Coal	1	0
Shale	1	4
Coal	0	6
Sandstone bands..	22	0
Coal	0	9
Shale	6	8
Ironstone in balls	0	3
Coal	0	3
Shale	1	0
Coal	2	1
Shale	4	2
Coal	1	5
Sandstone and shale	13	3
Coal (Blackbird)	3	11
Sandstone..	6	6
Coal (Coronation)	3	10
Sandstone and shale	51	6
Shale and ironstone balls	15	0
Coal (Hard Splint)	3	3
Shale and ironstone balls	6	5
Coal (Smithy)	2	9
Shale and sandstone	17	4
Fireclay and ironstone	4	1
Sandstone and bands	11	11
Coal (Bryants Splint)	5	8
Sandstone bands..	16	0
Coal	0	6
Sandstone and shale	21	11
Coal (Alecks)	2	7
Sandstone	10	8
Coal	1	1
Bands (sandstone)	12	2
Coal	2	6
Shale	1	5
Coal	0	11
Shale	4	0
Ironstone (clayband)	0	3
Coal (Kailblades)	1	3
Sandstone	2	1
Coal (Little Splint)	2	1
Sandstone and shale	56	0
Coal	1	0
Shale	21	0
Ironstone	0	9
Coal	2	1
Sandstone..	4	5
Coal	1	7
Sandstone and shale	11	3
Coal (Parrot)	3	0
Fireclay	1	0
Sandstone and shale	52	3
Limestone (No. 3).		
	673	5

Of the seams mentioned in the above section the chief can be recognised in the Lady Victoria and Emily shafts, as shown by the following considerably shortened sections:—

Portion of Section in the Lady Victoria Shaft.

	Ft.	In.
INDEX or No. 4 LIMESTONE.		
Strata	10	1
COAL	1	11
Strata	13	7
Shale, parroty 1 2		
CANNEL 0 2½		
IRONSTONE 0 3	2	9½
COAL 0 3		
CANNEL 0 7¾		
Shale, parroty 0 2		
Strata	22	4½
COAL	2	6
Strata	21	9
COAL	2	1
Sandstone	1	5
COAL	0	9
Bastard fireclay	5	8
COAL	4	0
Strata	11	4
Sandstone	20	10
GREAT SEAM COAL	6	9
Strata	4	8½
DIAMOND COAL	1	8
Strata	23	9
COAL	1	11
Daugh and blaes	3	3
COAL with daugh parting	2	3
IRONSTONE bands	2	5
COAL	0	6
Blaes	2	7
COAL	1	11
Blaes	2	3
LIMESTONE bands	2	5
Strata with thin COAL	20	9
COAL 1 4		
Blaes 0 11		
COAL 1 5	6	7
Blaes 0 9		
COAL 2 2		
Carry forward	204	9½

	Ft.	In.
Brought forward	204	9½
Strata	12	2
COAL, BLACKBIRD	1	5
Strata	20	3½
COAL with blaes parting	2	6
Strata with thin Coal	36	0
COAL, CORONATION	3	0
Strata	23	5
Bastard limestone	2	2
Blaes	12	2
COAL	1	9
Strata	51	4
SMITHY COAL	2	2
Strata with thin Coal	46	6
SPLINT COAL, waste	3	9
Strata with thin Coal	35	11
COAL with daugh parting	3	1
Strata	4	8
COAL	1	3
Strata	13	11
KAILBLADES COAL with partings of fakes	10	2
Strata	32	2
LITTLE SPLINT COAL	2	0
Strata	56	4
COAL	0	11½
Blaes	0	3
CANNEL COAL	0	10½
Strata	23	7
LITTLE COAL with blaes partings	5	3
Strata	17	7
IRONSTONE (the "bane")	0	3
JEWEL COAL, PARROT SEAM	1	3½
PARROT COAL, PARROT SEAM	0	8
BOTTOMS COAL, PARROT SEAM	1	0
WILD COAL	0	9
Strata	10	8
LIMESTONE.		
	646	0½

Portion of Section in Emily Shaft.

	Ft.	In.
INDEX or No. 4 LIMESTONE.		
Strata	20	11
COAL	1	7
Fireclay	5	0
COAL	1	1
Fireclay	10	5
COAL	2	1
Strata	46	8
Carry forward	87	9

	Ft.	In.
Brought forward	87	9
COAL	2	2
Fireclay	2	9
White sandstone	52	11
GREAT SEAM COAL	5	10
Strata	5	7
DIAMOND COAL	2	0
Strata	21	4
Carry forward	180	4

	Ft.	In.
Brought forward ..	180	4
Coal	2	4
Strata	23	3
Coal	2	3
Strata	29	8
Coal	3	3
Strata	13	0
Coal	1	6
Strata	17	1
Coal	0	11
Fireclay	0	11
Coal	1	10
Strata	9	3
Coal	1	1
Blaes	10	6
Coal	2	1
Strata	32	6
Coal	1	4
Strata	14	11
Coal	1	7
Strata	31	7
Splint Coal	3	9
Strata with thin Coal ..	36	8
Carry forward ..	421	7

	Ft.	In.
Brought forward ..	421	7
Coal	2	9
Strata	6	6
Coal	1	3
Strata	17	8
Kailblades Coal	3	10
Fireclay and blaes ..	2	6
Little Splint Coal ..	2	1
Strata	73	2
Coal { Rough	0	9
Coal { Parrot	1	3
Blaes	1	7
Ironstone	0	11
Blaes	14	11
Coal	2	1
Blaes	1	6
Coal	1	3
Ironstone bands	2	9
Blaes	9	7
Ironstone	0	2
Blaes	0	6
Parrot Seam	2	3
	570	10

If the Lady Victoria section be compared with that of Cowden it will be observed that in the latter the interval between the coals called the Blackbird and the Coronation is only 6½ ft., while in the former the interval between the same two coals is more than 58 ft. The thickness of the Edge Coal Group down to the Parrot Seam in the Emily shaft is about 50 ft. less than at Cowden, and a similar diminution of thickness in a southerly direction continues south of the Emily shaft (see p. 194).

The Parrot seam—the lowest of the Edge Coals—is not, on the average, more than 3 ft. thick, but it is often profitable to follow it to great depths as it contains, near the middle, a thin seam of Parrot which is a very good gas producer (1903), and the upper portion, the Jewel Coal, makes also an excellent house coal. At Arniston and Newbattle Collieries the Parrot varies between 6 and 9 in. in thickness, but farther north it becomes thinner, and in the old Cowden Pit is said to be only an inch. Above the Jewel portion of the coal we find 2 or 3 in. of dark, finely laminated shale containing abundant remains of *Lingula*, overlain by a band of ironstone, called the "bane," which is about 3 in. thick and is said to be very persistent. The ironstone makes a good roof to the coal workings and yields in places abundant remains of *Carbonia* (?). The *Lingula* shale was found in the Lady Victoria Pit, the Emily Pit, and an old level at Common (Gorebridge), and judging from the waste heaps at the tops of many of the old abandoned pits it must be of general occurrence in the Newtongrange and Gorebridge district.

The shale (blaes) 6 or 8 in. above the "bane" contains, in parts of the Carrington Dook of the Newbattle Colliery, lamellibranchs, determined by Dr. W. Hind to be *Naiadites carinata* and *Naiadites modiolaris*. This shale is believed to be the lowest

horizon in which these fossils have yet been found.* In England, they are said to characterise the Lower and Middle Coal Measures.

In the Lady Victoria Pit a band of hard calcareous sandstone,† about 5 ft. thick, is found 34 ft. below the Little Splint Coal, and contains along certain bedding planes an admixture of small black grains of tourmaline.

A thin seam of *Lingula* shale occurs in some places just above the Kailblades or Rough Coal, between 100 and 140 ft. above the Parrot Coal. It was stated to occur at Bryans by Mr. D. Milne Home,‡ so long ago as 1839, and is well exposed at Common (Gorebridge), where it is 2 or 3 in. thick and overlain by 15 in. of shale with ironstone nodules, but in the Lady Victoria Pit it has not been detected.

The Kailblades is used as a steam coal. In both the Emily and Lady Victoria Pits it is much mixed with partings of clay and thin-bedded sandstone, frequently full of vertical rootlets. The two coals, about 8 ft. apart, which are exposed in the old quarry at the north end of the wood between Lawfield and Langlaw, probably represent two portions of the Kailblades Coal with a thicker separation than usual.

A sandstone that occurs a little above the Kailblades Coal is about 40 ft. thick in the Masterton Quarry and contains numerous quartz grains as large as a pea, being much coarser than most of the sandstones which occur in this district in the Edge Coal group. In the Crossgatehall railway cutting there is, however, an equally coarse sandstone slightly below the Great Seam, and at Gilmerton the strata between the Great Seam and the Index Limestone chiefly consist of rather coarse sandstone or grit (p. 199).

The Bryans Splint Coal is sometimes 6 ft. thick, and is an excellent house coal. Parts of it are of hard splint coal which can be got in large blocks, and above it we often find 12 or 13 ft. of shale with small nodules of ironstone and thin even courses of sandstone.

The Coronation Coal in the Lady Victoria shaft is pyritous and somewhat liable to spontaneous combustion. About 24 ft. below this seam, a thin limestone, rather more than 2 ft. thick, was cut in sinking the Lady Victoria shaft. A search was made for this band in the "Newbattle incline," and a calcareous sandstone, 2 or 3 ft. thick, with abundant remains of *Productus semireticulatus*, was found between 20 and 30 ft. below the coal. This calcareous horizon is rather more than 300 ft. below the Index or No. 4 Limestone, and not far from the middle of the Edge Coal group. It is not recorded in the shaft section of the Emily Pit, Arniston.

In the roadway into Shaw's Quarry, a quarter of a mile slightly east of north of West Houses, three coals are exposed, varying between 14 and 24 in. in thickness and dipping about 24° to W.N.W., as well as a lower coal, 3 ft. thick, which has been worked by an "ingoing eye." All these coals must lie a little below the Diamond Seam and probably above the Coronation Coal in the Lady Victoria shaft, but they cannot be correlated confidently

* They occur on a higher horizon in the same group (p. 230).
† Locally called Wattie's toe. ‡ *Op. cit.* p. 38.

with coals shown either in that or in the Cowden section, the beds on this horizon being evidently very variable. At the entrance to the quarry the casts of two big tree stems—one of which is *Sigillaria*—are seen in a flaggy sandstone above the three-feet Coal. They stand almost at right angles to the bedding planes and are perhaps 4 ft. high. One of the stems must have been at least 2 ft. in diameter.

Limestone bands, about 30 in. thick, are stated to have been pierced about 40 ft. below the Diamond Coal in the Lady Victoria shaft. The beds on this horizon are not now visible in any part of the colliery, nor in any surface exposure in the neighbourhood. At Crossgatehall—four miles away—no corresponding calcareous band has been detected. The Diamond Coal is considered an excellent house coal though thin.

The Great Seam is 6 or 7 ft. thick at Arniston and Newbattle Collieries and near Smeaton Shaw. At the Arniston Colliery it is not of very good quality and is classed as a steam coal. In all these places it contains a band of parrot a little above the base, but this band is not of such good quality as that from the Parrot Coal, and at Arniston Colliery, where it is 3 in. thick, it is sent up separately. The Great Seam is exposed obscurely near the western end of the Crossgatehall railway cutting, where it contains, as usual, a band of parrot near the base: above the coal comes a rather massive sandstone about 30 ft. thick, which is well represented also at Gorebridge, Newtongrange and Cowden.

The Mavis Coal is exposed at the mouth of an old "boot gate" in a little wood at the junction of the roads a quarter of a mile S.S.W. of West Cowden. It is about 3 ft. thick and overlies a bed of shale, 20 in. thick, which rests on a sandstone, at least 35 ft. thick, coming above the Great Seam. Above the coal there is a bed of shale a foot thick, and then a band of ironstone from 4 to 5 in. thick.

Good surface exposures of the beds under review are rare. The best are those at Common (Gorebridge), in old quarries near East Houses and Lawfield, and in the railway cutting at Crossgatehall on the north-west side of the fault, with a large downthrow to the north-west, which crosses the cutting 90 yds. east of the bridge. The last-mentioned exposure furnishes the most extensive section, the details of which are given below in descending order:—

Section in the Eastern Part of the Crossgatehall Railway Cutting.

	Ft.	In.
Sandstone	2	0
Gap	1	0
Flaggy sandstone	1	6
Coal	1	0
Thin-bedded sandstone with rootlets	1	6
Massive sandstone	3	0
Coal	1	0
Sandy shale	1	0
Sandstone	2	0
Gap	15	0
Carry forward	29	0

		Ft.	In.
	Brought forward ..	29	0
Sandstone		30	0
Small Gap?			
BRIGHT COAL	GREAT SEAM	2	0
PARROT COAL	GREAT SEAM	1	1
BRIGHT COAL	GREAT SEAM	0	5
Sandy clay	GREAT SEAM	0	2
COAL	GREAT SEAM	0	6
Sandy clay		0	2
Gap .. .. 4 or		5	0
Shales and thin sandstones, often with rootlets		8	0
COAL		1	0
Shale		1	0
Alternations of sandstone and shale, the former rock in excess near the top		8	0
Shale		2	0
Sandy shale and shaly sandstone		6	0
Sandstone		30	0
COAL		0	2
Fireclay		5	0
Alternations of shale and sandstone		8	0
Shale with ironstone		8	0
BRIGHT COAL (bottom not seen)		1	11
Shale with ironstone nodules		10	0
Sandstone		4	0
Fireclay		0	10
COAL ..	JEWEL COAL of Carberry?	1	1
Clay shale	JEWEL COAL of Carberry?	0	8
BRIGHT COAL	JEWEL COAL of Carberry?	1	5
PARROT COAL	JEWEL COAL of Carberry?	0	6
Clay	JEWEL COAL of Carberry?	0	1
BRIGHT COAL	JEWEL COAL of Carberry?	0	11
Sandy clay		2	0
Massive sandstone		30	0
Blue and grey clay and shale, with ironstone layers and a 3-in. band of Parrot Coal close to top		15	0
Alternations of sandstone and shale		5	0
COAL		1	6
Mostly sandstone		6	0
COAL		0	10
Massive sandstone		25	0
COAL, splinty near top and with a 7-in. parting of shale near middle ..		3	0
Sandstone with rootlets		3	0
Shale		0	6
COAL with some Parrot near middle		2	9
Massive sandstone		11	0
Shale and thin-bedded sandstone		8	0
Massive sandstone		10	0
Thin-bedded sandstone with shale partings		5	0
Shale with ironstone		12	0
COAL with lumps of pyrites		1	6
Fireclay		1	0
		310	0

The total thickness amounts to about 310 ft. The coal with lumps of pyrites near the base of the section is seen on the south side of the railway cutting. On the north side a coal mixed with ironstone and parrot appears to be nearly on the same horizon, but the section here is not clear. The direction of dip varies between E.N.E. and N.N.E. and the angle between 25° and 30°.

The general dip in the Gorebridge-Cowden district is slightly

north of west at angles varying between 10° and 25°. Near Gorebridge, the outcrops are affected by the anticlinal fold of the Roman Camp ridge, at the south end of which the arch pitches to the south, and the dip changes gradually from west through south-west and south to south-east. Hence the outcrops of the lower coals—including the Bryans Splint, Kailblades and Parrot—form curves with the convexity pointing nearly south, but the crops of the Great Seam and overlying strata are abruptly truncated by the great Vogrie fault.

On the north side of East Houses the outcrops of the lower beds —from the Bryans Splint downwards—are also affected by a roll over towards the east, and though they are not distinctly seen they must in places be separated by wide intervals from those of the higher seams. Thus while the outcrop of the Edge Coal group on the west side of the Roman Camp ridge is slightly less than a mile broad near Newtongrange, it is a mile and a half near Cowden. The axis of the fold referred to strikes N.N.E., in much the same direction as that of the Roman Camp anticline.

On the south side of the old quarry at the north end of the wood between Lawfield and Langlaw the beds are plicated along two small folds with axes striking nearly east and west.

The Parrot Coal appears to have been formerly worked in at least two places nearly half a mile slightly north of east of Lawfield, and it is believed by miners to extend over the hill eastwards to Edgehead. It is said to have been proved in a boring a little west of the fault, with downthrow to east, which bounds the Edgehead workings.

The Vogrie N.N.E. fault, which has been adopted as the south-east margin of the area now being described, has, near Gorebridge, a downthrow to the north-west of about 40 fms. In the Vogrie Pit the depth of the Great Seam is 10 fms. and that of the Bryans Splint is 50 fms., while in a bore about 500 yds. south-east of the pit the Splint is only 6 fms. deep and is dipping gently north-west. The surface position of the fault can be located in the Gore Water, where there is an exposure of Limestone No. 4 a little distance on the north side of it. From a comparison of the underground with the surface positions the hade in this locality is made out to be 52°.

A little north of the Emily shaft two large nearly east and west faults throw the beds down into a trough. A quarter of a mile east of Hunterfield the displacement of the southern fault has been proved in the Bryans Splint Seam to be 186 ft. down to the north, but it rapidly diminishes in a westerly direction, and 730 yds. farther west, is only 18 ft. The northern fault is said to have a downthrow of 185 ft. near Greenhall, but about half a mile west of Greenhall the displacement in the Great Seam is only 90 ft. Eastward from Greenhall this fault truncates the limestone at the end of the Roman Camp ridge, but the downthrow cannot be large, the limestone on the south side of the fault having been found only a short distance below the surface.

At Bryans the strata are thrown down to the north 12 or 14 fms. by an east and west fault, which was lately exposed at the surface in a position 150 yds. north-east of the pit head; the crushed rock accompanying the fault is several yards in breadth.

An important line of disturbance striking north-east or N.N.E. and represented either by one or two faults, both with a large downthrow to the north-west, has been met in the Cockpen Dook, in the Newbattle Incline in the Lady Victoria Colliery, and in workings near East Houses. In the Cockpen Dook the fault plane has not been driven through, and the amount of downthrow is not known. The position of the south side of the fault in the Parrot Seam, at a depth of more than 2000 ft. beneath the surface, is about 30 yds. south of Cockpen Bridge. In the Newbattle Incline there are two large dislocations, one with a displacement of 240 ft. and another of 168 ft. Near East Houses the main fault has a throw of 120 ft. and is accompanied, on the south-east side, by a nearly parallel minor fracture of 30 ft. In a north-easterly direction from East Houses the disturbance has not been proved in mining, but it seems probable that it runs to the east of the outcrop of the Great Seam. Perhaps it is represented by the N.N.E. fault that crosses the Crossgatehall railway cutting, the downthrow of which is in a north-westerly direction, and must be large, perhaps as much as 500 ft., the greater part of the Edge Coal group being cut out by it.

A north-west fault on the south side of Wester Cowden has a downthrow to the north of 90 ft., and to the north of this locality two faults strike nearly north-west and have a displacement to south-west amounting to 30 and 42 ft. respectively.

The east and west fault passing about 100 yds. south of Cowden Cleugh * was formerly regarded as the continuation of the Sheriffhall fault. Perhaps it may be a branch of this great line of disturbance, but Mr. R. T. Moore has lately proved by boring operations that its downthrow is not likely to exceed 40 or 50 ft. at the head of the Cleugh. C. T. C.

COAL-FIELD EAST OF GOREBRIDGE AND OF THE ROMAN CAMP RIDGE.

North-east of the Gore Water, coals have been worked from the Vogrie Pits, two of which are situated on the western or downthrow side of the Vogrie fault and have worked the Parrot, Kailblades and Splint Seams. The Kailblades and the Splint have also been worked on the eastern side of the fault from three pits between Harvieston and Mountskip Farm. The Parrot Coal has been proved in bores but has not been worked on the eastern side, being apparently too thin to repay mining. This is indicated by the following section derived from an old bore put down near Harvieston, on the south-east side of the Vogrie fault:—

Section of the Strata at Harvieston.

	Ft.	In.
Surface	6	6
Fireclay	0	6
Sandstone and shale	5	5
SOFT COAL	0	7
Sandstone and shale	8	5
Carry forward ..	21	5

* Not named in the new edition of the one-inch map, but situated in the wood east of Cowdenfoot.

		Ft.	In.
	Brought forward ..	21	5
	Coal (impure)	0	4
	Sandstone	10	5
	Splint Coal (waste)	3	0
	Sandstone and shale	26	5
	Coal	1	3
	Sandstone and shale	24	9
Kailblades Seam.	Coal	1	4
	Fireclay	0	4
	Coal	1	7
	Fireclay	1	5
	Coal	1	8
	Sandstone and shale	91	6
	Parrot Coal	0	4
	Sandstone and shale	31	7
	Limestone.		
		217	4

It will be seen from the above that the valuable Parrot Seam of the Newbattle and Arniston Collieries is only 4 in. thick in this bore.

The Parrot Coal was formerly worked from a pit north of Hillhead on the downthrow side of the fault that traverses the Roman Camp ridge from Edgehead, where it has been proved in the coal workings, towards Mansfield. The coal that has been worked from the crop in the Camp Wood is considered by miners to be the Kailblades.

Within the limits of Sheet 32, Edgehead Colliery is the only place where coals are now worked on the eastern side of the Roman Camp ridge. The Splint Coal, which represents part of the Kailblades of Arniston, is the only seam being worked, but the Parrot Coal was formerly mined over a wide area from several pits near Edgehead. To the south-east of Edgehead the Cherry Coal, on a higher horizon than the Splint, has also been wrought. The Parrot Coal workings in this district have been carried as far north-west as the fault that runs E.N.E., between Mansfield and Edgehead, with a downthrow to the south. A second large fault, with a downthrow to the west, which may be a continuation of the Vogrie dislocation, has been met with in the workings about half a mile south-east of Edgehead, and limits the Parrot workings on the east.

The following section of the coals and intervening strata at Edgehead has been communicated by Mr. Johnston, Manager of the Edgehead Colliery:—

		Ft.	In.
	Strata	96	0
	Bains Coal	2	2
	Strata	24	0
Kailblades.	Rough Coal	2	3
	Strata	2	0
	Galls Coal	1	6
	Fireclay	1	2
	Splint Coal	2	2
	Strata (with Pit Coal)	108	0
	Parrot Coal	2	0

The general direction of dip in the Roman Camp and Edgehead district is south of east, but the same coals again outcrop with a contrary dip between Ford (Sheet 33) and Vogrie, where they overlie

the lower limestones exposed in the valley of the Tyne Water. The Kailblades Coal is exposed in the burn north of Vogrie House a short way below the bridge over which the main road passes. The same coal is cut near the mouth of the long day-level that runs from the Level Pit near Chesterhill to the Dewar Town Burn, and is also to be found in the burn section above the mouth of the day-level. A bore put down just below the outcrop of the Kailblades Coal in the Vogrie Burn reached the Parrot Coal, which is visible in the burn section not far above the bridge at Vogrie House. A coal formerly worked near the Cotty Burn, about a quarter of a mile above the road, is also considered to be the Parrot Coal. The old workings are still to be found near the burn, and the coal appears to lie a short distance above the limestone exposed a little lower down the burn.

In a quarry north of Fordel Park, a coal 5 ft. thick is met with, but no reliable information has been obtained about it. This seam may probably be on a higher horizon than those worked at Edgehead, and it may be the Five-foot Coal of Ormiston.

Two coals were formerly worked in a shallow pit at Hadfast, near Cousland, but their position is not accurately known. The following is the section of the pits:—

		Ft.	In.
	Various strata	27	0
	Coal	1	6
	Various strata	30	0
	Shale (roof)	3	0
Wood Coal	Coal (Parrot)	0	4
	Coal (hard)	2	0
	Stone mixed with coal	2	0
	Coal	1	8
	Various strata	30	0
	Shale (blaes roof)	7	0
Hammersley Coal.	Coal	1	0
	Stone	0	3
	Coal	1	8
	Stone	0	8
	Coal	1	3
		109	4

It is said that in earlier times six coals were wrought between Hadfast Burn and the stream to the north, by driving in at the crop on the north brow of the former, and draining by a "day-level" from the latter stream. These coals all dip to the north, and are the equivalents of some of the lower coals in the series, but the information is too scanty to enable them to be identified. C. B. C.

CARBERRY AND PRESTONGRANGE FIELD.

The Edge Coal seams are wrought from Carberry, Wallyford, Prestongrange and Northfield Collieries, the last mentioned being just south of the west end of Prestonpans. They were also formerly wrought from Dolphingston Colliery, situated beside the railway, north of Dolphingston.

A large fault with a downthrow to the south-west, traverses the strata a short distance to the south of Carberry Tower, which is a

continuation of one formerly known to exist in the Coal Measures to the west, but, near Carberry, the amount of its displacement has increased to about 100 fms. The outcrops of all the coals are shifted by it to a considerable extent. Another dislocation, with a down-throw to the north of 25 or 30 fms., diverges from the main fracture near Carberry Mains, and intersects one of the shafts at Carberry Colliery, where the seams worked are, in descending order, the Great Seam, the Carberry or Wallyford Jewel, the Four-foot and the Five-foot. The outcrops of all these coals are indicated in the map. A thinner seam, called the Parrot Rough, and containing Parrot, occurs a short distance under the Jewel. The dip of these seams near their outcrop is about 20° or 25°, but they flatten out towards the centre of the basin:—

Section of the Strata at Carberry Colliery.

	Ft.	In.
Limestone (No. 4) Index.		
Blaes with coal streak	1	2½
Sandstone	11	4
Blaes	5	0
Coal	0	4
Blaes	5	0
Coal (Deception)	1	9
Blaes	3	0
Sandstone	3	0
Blaes	4	6
Bands	4	4
Blaes	3	6
Sandstone	6	5
Coal (Cryne)	2	5
Sandstone	8	10
Black blaes	2	6
Sandstone	17	3
Sandstone and shale	3	5
Coal	1	2
Fireclay	2	6
Fakes	2	8
Coal	1	0
Fireclay	8	9
Sandstone	20	0
Coal (Great Seam)	9	0
Sandstone	6	0
Dark fakes	3	0
Blaes	6	6
Coal	1	2
Sandstone	8	3
Fakes	6	0
Blaes	5	0
Ironstone band	0	4
Coal	0	2
Fireclay	5	0
Fakes	5	9
Sandstone	32	2
Coal	0	4
Banded fireclay	7	0
Bands	7	4
Strata	9	1½
Coal (Jewel)	3	11
Fireclay	6	4
Light fakes	3	2
Hard blaes	1	6
Coal (Parrot Rough)	2	3
Bands	7	4
Hard blaes	1	4
Coal (Two-Foot Cherry)	1	4
Fireclay	1	6
Dark fakes	2	7
Hard sandstone	4	11
Dark fakes	3	2
Parrot Coal (coarse)	0	3
Blaes	3	0
Light fireclay	3	6
Sandstone and shale	9	2
Coal	1	4
Blaes	2	3
Coal	0	6
Sandstone and fakes	13	11
Black blaes	1	0
Soft fireclay	0	6
Coal (coarse)	1	0
Hard fireclay	1	2
Coal	1	6
Black blaes	0	6
Sandstone	12	2
Coal (Four-Foot Seam)	3	5
Sandstone	14	9
Fakes and sandstone	10	9
Sandstone	10	9
Fakes and sandstone	5	3
Dark fakes	22	2
Coal	1	9
Fireclay	3	8
Coal (coarse)	0	6
Sandstone and shale	4	1
Ironstone balls	0	4
Coal	1	7
Sandstone	7	9
Dark fakes	2	0
Blaes	4	0
Parrot Coal (coarse)	0	7
Sandstone	5	3
Blaes	1	10
Fireclay	6	0
Blaes	6	6
Coal (Five-Foot Seam)	3	7
Fakes and sandstone	31	6

	Ft.	In.
Coal and blaes	2	1
Sandstone	6	6
Coal	0	10
Soft blaes	0	2
Sandstone	13	10
Coal	0	11
Sandstone	36	8
Ironstone	0	4
Coal	0	5
Fakes	10	3
Coal (with partings) perhaps Kailblades.		
	543	1

The Diamond Coal, which lies immediately below the Great Seam at Cowden, may be represented by the thin seam 14 in. thick in the foregoing section; or it may here correspond with the bottom portion of the Great Seam. Below the Diamond, in the Cowden section, the first thick coal is the Siller Willie, which apparently does not exist in the Carberry field, for the Jewel is too low down in the series, and is probably the equivalent of the Blackbird or the Coronation Seam. The Five-foot seam of Carberry may correspond to the Bryans Splint of Newbattle and Cowden, while the coal at the bottom, which has only been reached by boring, may correspond with the Kailblades.

Between Carberry and Wallyford Collieries the strata are affected by another fault, with a downthrow of 30 fms. to the north. At the latter colliery the coals worked at present are the same as those at Carberry. Above the Great Seam there is a bed of blackband ironstone, not found in the Carberry section, but occupying here the same position as a band of ironstone already referred to as lying above the Great Seam on the west side of the basin at Loanhead and Mauricewood (pp. 208, 211). Two bands of Parrot occur a short distance below the Great Seam, and were formerly wrought. The upper one is underlain by ironstone, while just above it Mr. Tait has discovered a bed containing remains of *Naiadites obesa*.

A noticeable difference occurs in the thickness of the strata between the Great Seam and the Jewel at Carberry and Wallyford. At the former locality they measure roughly 100 ft., and at Wallyford, a mile and a half distant, nearly 180 ft.

Between Wallyford and the sea at Prestongrange the strata are interrupted by two moderately large faults, as well as by others of smaller magnitude. The first of these was proved from the now abandoned Dolphingston Colliery, where it crosses the strata in a north-west and south-east direction, and has a downthrow of 15 fms. to the south-west. The other, which has been proved from Prestongrange, runs east and west, and throws down the strata 30 fms. on the north. At Dolphingston and Prestongrange the strata lose for a time their prevalent northerly strike, and the outcrops swing round to the east.

The following section of the coals at Dolphingston Colliery, all below the position of the Great Seam, has been kindly communicated by Mr. M'Millan, Manager of the Elphingstone Collieries:—

		Fms.	Ft.	In.
Coal	3 ft. 9 in. at	13	4	9
„	3 ft. at	22	1	0
„	4 ft. 5 in. at	26	1	1
„	2 ft. 2 in. at	28	0	1
„	2 ft. at	36	4	7
„	1 ft. 8 in. at	46	5	6
„	2 ft. at	50	1	9

		Fms.	Ft.	In.
Ironstone	1 ft. 6 in. at	53	1	3
Jewel Coal	4 ft. 6 in. at	58	0	0
Beggar Coal (with ironstone bands for roof) ..	3 ft. 6 in. at	63	3	6
No. 1 Diamond Coal (including a 1-in. parting)	2 ft. 2 in. at	73	3	6
No. 2 Diamond Coal (including a 6-in. parting)	3 ft. 1 in. at	89	0	6

This section corresponds very well with that of Northfield Colliery. The coal at a depth of 22 fms. 1 ft. is probably the same as the Wallyford Jewel, and is represented by the Clay Seam of Northfield and Prestongrange. The coal at 36 fms. 4 ft. 7 ins. is the Four-Foot of Wallyford and Carberry.

The Jewel Coal mentioned in this section is the equivalent of the Jewel seam at Prestongrange and Northfield, and of the Five-foot Coal at Wallyford, but the Jewel of Wallyford is on a much higher horizon. The former also corresponds with the coal which is called the Five-foot in the western part of the East Lothian coal-field; and may be the same as the Panwood Coal of the Penston district. If this last supposition be correct, the ironstone above the Jewel Coal in Dolphingston Pit occupies a somewhat similar position to the Penston Ironstone.

At Prestongrange the principal coal seams in descending order are as follows: Great Seam, Diver, Clay Seam, Five-foot, Smithy, Jewel, Beggar, and Diamond No. 1. The seams most wrought are the Great Seam and the Jewel, both of which are mined for a considerable distance underneath the sea. The Great Seam contains a band of clear coal, which is picked out for household purposes. The Clay Seam is also wrought, principally on account of a fireclay underneath it, which is used in the adjacent brick and fireclay works. Diamond No. 1 is the equivalent of the seam that receives that name at Dolphingston. It probably corresponds to the lowest coal given in the Carberry section, and may thus be the same as the Kailblades of Newbattle. At Prestongrange, 2 in. of shale, full of remains of *Lingula*, have been found to occur above it.*

At Northfield Colliery the strike of the strata is again more northerly, and to the north of this locality the outcrop of the Great Seam runs out to sea, but is repeated again on the foreshore, close to the edge of the map, by a series of small faults.

In Northfield Colliery the succession from above is as follows: the "Wee" Coal, Great Seam, Diver, Clay Seam, Three-foot, Four-foot, Jewel, and Beggar Seams. From a shale occurring just above the Jewel Seam at this colliery Mr. Tait has obtained specimens of *Naiadites modiolaris* and *Naiadites carinata*. He has also found a similar shale containing lamellibranch remains above the Jewel Seam at Bankton Colliery, which is situated to the east of Northfield Colliery and just outside the limits of the present map. At both places the most abundant fossil is *N. modiolaris*.

The suggested correlation of the coal seams at the collieries in this district is given in the following table, but it must be borne in mind that it is attended with a large element of uncertainty:—

* A similar shale with *Lingula* occurs above the Kailblades Seam at Bryans and Arniston (p. 221).

Newbattle and Cowden.	Carberry and Wallyford.	Prestongrange.	Dolphingston.	Northfield.
—	—	—	—	"Wee" Coal
Great Seam	Great Seam	Great Seam	—	Great Seam
—	—	Diver	Coal, 3 ft. 9 in.	Diver
Blackbird or Coronation	Jewel	Clay Seam	,, 3 ft.	Clay Seam
—	Parrot Rough	Five-Foot	,, 4 ft. 5 in.	Three-Foot
—	Two-Foot Cherry	Smithy	,, 2 ft. 2 in.	Four-Foot
—	Four-Foot	—	,, 2 ft.*	—
Bryans Splint	Five-Foot	Jewel	Jewel	Jewel
—	Beggar (at Wallyford)	Beggar	Beggar	Beggar
Kailblades	Coal reached in bore at Carberry	No. 1 Diamond	No. 1 Diamond	—
Parrot	—	—	No. 2 Diamond	—

East of the lines of outcrop of the coal at Carberry and Wallyford, the strata bend over a continuation of the Roman Camp anticline, along the centre of which the bands of limestone which are seen in the Crossgatehall railway cutting can never be very far from the surface. To the east of this anticline evidence shows that the coal seams, including the Great Seam at one point, come in again within the limits of the map. The outcrops, however, are extremely uncertain.

The earliest reliable evidence of the working of coal in Scotland refers to the area just described. In a charter given by Seyer de Quinci, Earl of Winton, to the monks of Newbattle, which must have been granted between 1210 and 1219, mention is made among other things of a coal heugh, located somewhere between Pinkie and Prestonpans.† Through Prestongrange, Wallyford and Carberry the Great Seam was formerly wrought by means of a day-level from the sea at Prestongrange. Its outcrop could at one time be traced by means of the subsidence of the surface into the old workings, which were carried as far as the fault which runs through one of the shafts at the present Carberry Colliery. By this level the coal is said to have been wrought out to a depth of 23½ fms. E. M. A.

The Upper Limestone Group.

The base of this group, as already indicated, is marked by the Index Limestone (No. 4), and its top by the Castlecary Limestone (No. 6). It comprises three or four beds of marine limestone together with four, five, or six seams of coal above a foot thick, interstratified with sandstone, shale and fireclay. The limestones are generally thin and impure and have never been wrought to any great extent. On the west side of the basin the bottom coal is called the South Parrot and is a valuable seam, about half of it at Niddrie Collieries being composed of parrot of good quality.

*At 36 fms. 4 ft. 7 ins.

† R. W. Cochran-Patrick, "Early Records of Mining in Scotland," 1878, Introduction, p. xliii.

The limestones are generally more largely developed at the south-western and south-eastern ends of the basin than towards the north. In the neighbourhood of Niddrie, at the north-west side of the syncline, they are thicker than at the east side, though the sediments separating them are also thicker—a somewhat unusual coincidence.

C. T. C.

PORTOBELLO, NIDDRIE AND GILMERTON AREA.

The Niddrie railway cutting, where the beds are well exposed and have a uniform dip of about 65°, affords an almost complete section, as shown below :—

		Ft.	In.
Castlecary or No. 6 limestone.	Limestone (lower part white and encrinital)	7	0
	Gap	9	0
	Limestone	3	0
	Gap with some sandstone	112	2
	Coal	0	4
	Sandstone and fireclay	4	8
	Gap	7	8
	Alternations of shale, fireclay and sandstone	15	5
	Gap	2	8
	Sandstone and shale	9	11
	Coal	0	1
	Sandstone and fireclay	8	9
	Coal	1	0
	Shale, fireclay and sandstone	26	11
	Coal	0	7
	Fireclay and sandstone	2	1
	Gap (position of Allans Coal ?)	1	9
	Sandstone	35	0
	Shale	17	0
	Sandstone	3	3
	Coal	0	1
	Fireclay, sandstone and shale	6	5
	Fireclay and shale	21	0
	Sandstone (faky)	47	9
	Dark shale	14	0
	Arden or No. 5 limestone	3	5
	Sandstone and shale	3	9
	Grey shale	7	10
	Sandstone	23	10
	Dark shale	11	7
	Flaggy sandstone	15	2
	Fireclay with shale	23	7
	Coal	1	2
	Fireclay and sandstone	3	3
	Coal streak		
	Sandstone and shale	5	6
	Massive yellow sandstone	8	10
	Shale	2	7
	Coal (Wood)	2	6
	Fireclay	10	10
	Soft creamy sandstone	54	2
	Gap (with excavation near top)	27	4
	Sandstone	16	11
	Gap with sandstone	30	7
	Grey shale with ironstone nodules	43	10

		Ft.	In.
The "Extra" Limestone.	Limestone	2	2
	Grey marl	5	5
	Limestone	0	7
	Grey marl with *Productus latissimus* very abundant near base	7	11
	Limestone with *P. latissimus*	1	0
	Grey fossiliferous marl	2	4
	Coal	0	2
	Fireclay	3	8
	Gap with sandstone and shale	25	0
	Sandstone	25	0
	Fireclay	5	0
	Coal	0	2
	Sandstone and marl	10	9
	Soft, crumbly, often coarse, salmon-coloured grit	63	0
	Shale	4	6
	Coal	0	6
	Fireclay	0	8
	Coal	0	6
	Sandstone and shale	14	0
	Coal	0	4
	Fireclay	10	0
	Flags	13	0
	Shale and sandstone	14	3
	Flaggy sandstone	42	4
	Gap	2	8
	Bluish-grey shale	18	0
	Hard flaggy sandstone	1	10
	Fireclay passing into sandy shale	9	0
	Sandy root-bed	2	8
	Gap (position of South Parrot Coal)	5	10

The beds below the South Parrot are not so well exposed in the railway section as they were in the crosscut of No. 13 Niddrie Pit, from which the following section has been constructed:—

		Ft.	In.
South Parrot Coal.	Splint	1	10
	Parrot	1	0
	Sandstone and fireclay	6	9
	Coal	0	3
	Sandstone	91	0
	Blaes with abundant ironstone nodules	18	0
	Index or No. 4 limestone	3	4

It will be seen from the foregoing section that the Upper Limestone group at Niddrie has the great thickness of 1068 ft. and includes four limestones and several coals. The interval between the Castlecary and Arden Limestones amounts to 338 ft. 6 in.; that between the Arden and the "Extra" Limestone to 293 ft. 3 in.; and that between the "Extra" and the Index to 391 ft. 8 in. Three of the coals have been wrought, namely, the Allans seam lying between Limestones Nos. 5 and 6, the Wood between Limestone No. 5 and the "Extra," and the South Parrot between the "Extra" Limestone and No. 4. The position of only the last of these three coals is known with certainty in the Niddrie railway cutting, where it overlies a thick sandstone which is very persistent over the Lothians and may be named the Joppa Sandstone, as it has been largely wrought in the Joppa Quarry. It corresponds with the well-known Bishopbriggs Sandstone of the Glasgow district. The conditions favourable for

the formation of limestone did not cease at Niddrie with the formation of No. 6 Limestone, for a limestone 3 ft. 6 in. thick occurs about 23 ft. above it, which is regarded as part of the Roslin Sandstone series (Millstone Grit). The "Extra" Limestone between Limestones Nos. 4 and 5 consists of a mass of white fossiliferous marl with thin irregular courses of limestone, both of which are richly charged with *Productus latissimus*. The same fossil occurs again abundantly in No. 4 Limestone (Index); at Joppa Quarry and Niddrie cutting it occurs in a band at the bottom of the limestone, while in the crosscut from No. 13 Pit of the Niddrie Colliery it is at the top.

A portion of the group is well exposed in the railway cutting east of Gilmerton Station. The section is very clear between No. 5 and the "Extra" Limestone, and continues to some distance below the latter. The chief details are shown in the following section in descending order:—

	Ft.	In.
No. 5 LIMESTONE	4	0
Sandstone and shale	51	0
Dark shale	35	0
IRONSTONE band	1	6
Shale, sandstone and fireclay	9	6
WOOD COAL	2	3
Sandstone and shale	49	0
Sandstone, reddish	70	0
Gap, at least	30	0
The "EXTRA" LIMESTONE (fossiliferous marl with LIMESTONE courses, with abundant *Productus latissimus*)	23	4

The Index Limestone (No. 4) is not exposed in the cutting, but its position is known from the position of the South Parrot Coal in the mines.

The upper portion of the group is well shown on the foreshore at Portobello (see Plate VII.), where the beds exposed consist of sandstones with intercalated fireclays and shales and at least two seams of coal, one of which, 366 ft. below No. 6 Limestone, is 5 ft. thick. About 115 ft. above this horizon is a band of parrot shale, which burns freely. The dip varies from 55° to 57°.

No. 6 Limestone is very well shown on the same foreshore, where it is divisible into the following portions:—

	Ft.	In.
LIMESTONE, dolomitic	5	0
Dark shale	3	6
LIMESTONE, blue earthy	4	6

Some dark shales overlying the dolomitic limestone are sharply twisted, and the dip is locally reversed.

In the shale forming the roof of the South Parrot Coal, Dr. Traquair * detected a fragment of a *Lingula* and remains of twenty-three species of Lower Carboniferous fossil fishes, which all belong to the estuarine type. He emphasises the resemblance which exists between them and those obtained from the Borough Lee (Rumbles) Ironstone (above the Great Seam). The shale and the ironstone contain seven species which have not been recorded from any horizon below the Great Seam. W. G., E. B. B.

* *Op. cit.* p. 696.

LOANHEAD, BILSTON BURN AND MAURICEWOOD AREA.

The sequence of limestones, coals and intervening strata in the Upper Limestone group in this district is given in the subjoined table:—

	Ft.	In.	Ft.	In.
Castlecary limestone (No. 6)	11	3		
Strata			2	10
Coal	0	6		
Strata			10	3
Coal	1	0		
Strata			137	7
Coal	1	0		
Strata			19	6
Coal, Parrot	1	2		
Strata			55	4
Coal	0	1		
Strata			27	5
Arden limestone (No. 5)	5	0		
Strata			40	11
Coal	0	1		
Strata			128	0
limestone } "Extra"	3	6		
Strata } limestone			36	0
limestone	2	2		
Coal, Parrot	1	0		
Strata			80	1
Coal	0	6		
Strata			5	8
Coal	3	0		
Strata			80	5
Coal	1	0		
Fireclay and blaes			3	1
Coal	1	0		
Blaes			2	8
Coal	0	6		
Strata			4	8
Coal } South	2	9		
Fireclay } Parrot			2	3
Coal	0	3		
Strata			13	8
Coal	0	6		
Strata			78	4
Index limestone (No. 4)	10	10		
	47	1	728	8

The Index Limestone in the Bilston Burn lies 102 ft. above the Flex Coal and is well exposed in the stream below the end of the heap connected with the disused Dryden Pit. Here it is a brown limestone, 10 ft. 10 in. thick, which shows a few specimens of *Productus latissimus* (see Fig. 15). It is covered by yellow sandstone and fakes, which are overlaid in turn by a coal, 6 in. thick, and a grey sandstone full of plant remains. The thickness of 5 ft. 3 in. given to the South Parrot Seam in the above table includes a parting of fireclay 2 ft. 3 in. thick near the base. Between Edgefield and the

Bilston Burn this seam is of variable thickness, as shown by the following comparative sections:—

At Edgefield.	Ft.	In.
Coal, Parrot ..	1	3
„ Free ..	0	10
	2	1

At Mavisbank.	Ft.	In.
Coal, Fine Splint	1	4
„ Parrot ..	0	5
„ Rough Rich	1	3
	3	0

Bilston Burn.	Ft.	In.
Coal	2	9
Fireclay ..	2	3
Coal	0	3
	5	3

The band of parrot in this seam at Mavisbank was a gas coal of good quality and was sold, together with the upper and lower portions, for household purposes. At Edgefield the parrot was also an excellent gas coal, one ton producing 11,454 c. ft. of gas of 30 candle power. On both sides of the Bilston Burn the crop can be traced by the old workings extending to the top of the wooded bank.

Continuing this stream section (Fig. 15) we find, about 93 ft. above the South Parrot Seam, a coal, 3 ft. thick, which may be the Wood Coal, but it has not been wrought in this field. It is succeeded by a set of thick sandstones with partings of blaes. A rough parrot coal, 1 ft. thick, appears at the junction of the Dryden and Bilston Burns, and lies exactly at the base of the Extra Limestone, which consists of several bands. The impure limestone at the base is 2 ft. 2 in. thick, and is separated by 36 ft. of limy blaes from a good limestone 3 ft. 6 in. thick.

In the Dryden or Kill Burn the Extra Limestone has been traced up stream almost to Dryden House, where both the top and bottom beds and also the limy blaes are exposed. Near the foot of this tributary *Productus latissimus* occurs more abundantly in the Extra Limestone than in the exposure of the Index Limestone in Bilston Burn. From the junction of the two streams the parrot coal and limestone, together with the underlying thick sandstones, can be followed down the Bilston Burn for 190 yds. until they are shifted by a small fault to the south side of the ravine (Fig. 15). At this point the stream bends to the north and at the same time the outcrops of the limestone and parrot coal run up the side of the ravine and pass in below the viaduct at the foot of the south embankment. On the south side of the ravine and 31 yds. below the centre of the viaduct the parrot coal is seen, followed by 35 ft. of limy blaes and some sandstone ribs. Here the section is interrupted by one of the Burghlee faults, but the beds on either side can easily be identified. Above this Extra Limestone we find 170 ft. of strata composed of sandstones and blaes with a soft coal, 1 in. thick, and succeeded by the Arden Limestone. This calcareous zone is here a light grey calmy rock, full of crinoid stems, is 5 ft. thick and occurs in two beds. About 253 ft. of strata, consisting of an alternating series of blaes, bands, sandstones and fireclays, with five thin coals, lie between the Arden and the highest limestone (Castlecary) of the group, which is well exposed on the south side of the stream about 50 yds. below a dilapidated stone bridge, its thickness there being 11 ft. 3 in. Between this outcrop and the bridge the beds are sharply folded and occasionally dip west (Fig. 15).

In the area to the south of Bilston Burn the first exposure of any

of the upper limestones is that of the Castlecary Seam on the east side of the river Esk above the Roslin Powder Mills, but the section is not very satisfactory nor is the structure of the ground clear. In the small stream at Greenlaw Mains two beds of encrinital limestone, nearly vertical, have been quarried, but very little rock is now visible. From the depth at which the No. 3 Ironstone has been mined below these calcareous zones it is inferred that the limestone nearest the railway may be the Arden and the other to the north-west the Extra Limestone. To the south of Mauricewood Pit the crops of the Castlecary, Arden and Index Limestones have been laid down by protraction from boring information. In the Coates Burn, a mile west of Penicuik, two outcrops of the Calmy or Arden Limestone are seen in the bed of the stream on either side of a shallow syncline. A short distance below the eastern limb of this trough is a grey-blue limestone with calmy blaes and ironstone nodules, which probably represents the Extra Limestone. Two hundred yards farther down the stream the Arden Limestone appears again on the eastern side of an anticlinal fold. J. S. G. W.

PENICUIK AREA.

The highest or Castlecary Limestone is seldom exposed in the south-west part of the basin, and the exact position of the upper limit of the Carboniferous Limestone in this drift-covered area is consequently, over a large extent of its course, conjectural.

The Castlecary Limestone crosses the river Esk at Esk Mills, half a mile below Penicuik, where it appears as a hard grey encrinite rock, with a dip to north-west at 16°. From this point it extends north-eastward and is exposed in the small burns to the east and north-east of Auchindinny Mains. In the stream which flows past Firth House it presents the character of a brown-weathering, somewhat sandy limestone, characterised by *Productus costatus* and abundant Spirifers. A short distance south of Kirkettle it is cut off by the fault which forms the southern boundary of the Roslin Sandstone.

In each of these exposures, as at Esk Mills, the limestone is immediately overlain by a dark shale with ironstone nodules, to which succeeds a thick false-bedded yellow sandstone. Beneath the limestone in the Esk section follow sandstones, dark shales and a thin coal 10 in. thick.

Two hundred and fifty yards farther south another limestone, the Arden or No. 5, crosses the stream, and occurs here in two bands separated by a few feet of shale and sandstone. The upper bed is only 9 in. in thickness, but very fossiliferous, the lower a hard grey calmy limestone 9 ft. thick. It is also well seen in the bank of the mill lade on the west side of the river, where it is crowded with *Productus latissimus*.

There is no evidence of the occurrence of this band in the ground to the north-east, but its approximate position at the Rosewell Asylum on the east side of the basin of Millstone Grit has been fixed by the bores near Auchindinny Mains. The grey calmy limestone, seen in the ditch at the back of Pomathorn Station, no doubt represents the Arden Limestone, thrown back to the south-east by the fault that crosses the Esk at the Valleyfield Mills. The brown-weathering encrinite

limestone that crosses the Black Burn below the bridge at Dykeneuk appears to occupy the position of the Castlecary band, and is succeeded above by the usual shales with ironstone ribs and yellow sandstones. There are two calcareous zones at this locality, but the distance between them seems too small for the lower one to be regarded as the Arden. These upper limestones are not seen again on the east side of the Auchencorth basin.

The Index Limestone is also not visible anywhere in the ground to the east of Penicuik, but its approximate position, as indicated on the map, has been obtained from bores.

The strata are here inclined to the north-west at low angles, and it will be noticed how far the outcrop is shifted to the west by the Valleyfield fault.

The exact position of the highest limestone on the west side of the basin south of Penicuik can be nowhere fixed with certainty, but the Arden and Index can be traced fairly continuously from the grounds of Penicuik House nearly to the margin of the map. The former crosses the Esk one-third of a mile east by north of Penicuik House and can be followed along the steep wooded bank above the south side of the river. It here forms two bands, separated by at least 50 ft. of shales and sandstones, and dipping south-east at 50° to 55°. Immediately above the upper band is a thin coal.

The Index Limestone is exposed in the small burn north-east of Penicuik House and in the river at the saw mill, *P. latissimus* being abundant at both localities. A fault with a downthrow to the east crosses the river between the saw mill and the cauld, cutting off the outcrop of the Index Limestone in the bed of the stream, and throwing out the Arden from the Hare Burn section, where it would naturally appear between the base of the Roslin Sandstone and the South Parrot Coal. The position of these limestones on the west side of the fault is for some distance obscured by drift and alluvium, but there are indications that the Arden follows the outcrops of the underlying Wood and South Parrot Coals round the steep contours of the Hurly wood.

A dark-blue limestone and calcareous shale, crowded with very fine specimens of *P. latissimus* in the Cornton Burn at Cornton, is recognised as the next appearance of the Index Seam, and half a mile to the south-west, both this limestone and the Arden, with their intervening coals, are seen in the bank of the river a short distance below Brunston Farm.

From this point the two limestones with either one or both of the associated coals can be traced almost continuously along the river-banks to Auchencorth. To the west of Brunston Castle the beds are thrown into a series of gentle synclinal and anticlinal folds. The Arden Limestone, brought up again on the back of one of the latter, is well displayed in the small stream that falls into the Esk just below Auchencorth. The section here shows 8 to 9 ft. of brown-weathering calmy grey limestone with an anticlinal dip to north-west and south-east at about 20°. This band contains *P. latissimus* and *Cauda-galli*, and in the outcrop on the steep bank across the river, in addition to *Productus*, there is a remarkable bed of cup-corals.

The Arden, the Wood Coal and Index Limestone can be followed for some distance farther to the south-west along the steep river-

banks, till they leave the valley and are lost beneath the drift and peat that covers the Auchencorth plateau.

The Wood and South Parrot, the most important of the coals associated with the Upper Limestones, are seen in the Hare Burn, half a mile south of Penicuik House. The upper seam, the Wood, is here about 19 in. thick, and the Parrot, a short distance below, gives 10 or 12 in. of parrot coal. The lower seam was worked about the year 1866 to supply cannel coal for the gas-works at Penicuik House, but was found to be poor in quality. It will be noted that these coals have decreased in thickness between this point and Niddrie, where the Wood is 2 ft. 6 in. and the Parrot 2 ft. 10 in. in thickness. The section above the coals in the Hare Burn gives a series of shales, fireclay and sandstones, with a band of clayband ironstone near the edge of the wood—which is almost immediately followed by the red and purple grits of the Roslin Sandstones, the two higher limestones being cut out by a fault. This section is noteworthy as having yielded, in addition to undoubted Lower Carboniferous forms, fish remains pronounced by Dr. Traquair to be "indistinguishable from *Strepsodus sauroides*," a form hitherto only recorded from Upper Carboniferous strata. In addition to this fish, Mr. Tait has obtained from a bed of rusty sandstone with ironstone nodules, between the clayband ironstone and the upper coal, the following:—

Acanthodes sp. (very large spines of).
Oracanthus armigerus *Traq.*
Elonichthys pectinatus *Traq.*
Helodus sp.
Cochliodont teeth and spines.
Calamites sp. nov. [=C. Taitianus *Kidston M.S.*].

L. W. H.

ARNISTON MAINS, GOREBRIDGE AND SMEATON AREA.

In this tract there are few exposures of the Upper Limestone group, but the whole thickness of this division has been proved in the Cowden Colliery and New Mills level (Dalkeith), and in the Lady Victoria Pit (Newtongrange). The bottom portion has also been proved in the Emily Pit, Arniston. None of the coals in the group is at present worked in this district.

The section in Cowden Colliery and New Mills level,* and also that in the Lady Victoria Pit, are given below in an abbreviated form:—

Section of Upper Limestone Group in Cowden Colliery and New Mills Level.

	Ft.	In.
LIMESTONE (No. 6)	2	5
Hard shale	9	0
Red sandstone	24	0
Shale and ironstone	7	0
COAL	1	8
Sandstone..	19	0
Carry forward ..	63	1

* This section is given in the "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861, p. 102. It differs considerably from that given by Mr. Milne Home (*op. cit.* table facing p.129), in which a 4-in. limestone is placed about 119 ft. above the Great Seam and about 533 ft. below Limestone No. 6. Between these two limestones comes an intermediate one about 154 ft. below No. 6.

	Ft.	In.
Brought forward ..	63	1
Shale	1	0
COAL	0	6
Sandstone	15	3
COAL	1	2
Shale and sandstone	76	6
LIMESTONE (No. 5)	2	11
Sandstone and shale	48	0
COAL	1	9
Shale	6	0
Sandstone	46	0
Shale	60	0
Sandstone	25	0
Shale with streaks of coal	19	9
Alternate beds of sandstone and shale	77	0
COAL	3	0
Grey sandstone and shale in bands	8	0
COAL	1	5
Sandstone	84	0
LIMESTONE	0	4
White sandstone	12	0
Shale	2	0
COAL	0	4
Shale and sandstone	3	0
Sandstone in beds	7	0
Shale	0	6
COAL, fine splint	1	9
Sandstone bands	6	0
Shale and ironstone	7	0
Sandstone	94	0
LIMESTONE (No. 4)	4	8
	678	11

*Section of Upper Limestone Group in Lady Victoria Pit.**

	Ft.	In.	Ft.	In.
CASTLECARY or No. 6 LIMESTONE	3	5		
Strata	121	1		
COAL	0	10		
Bastard fireclay	9	5	218	6
Sandstone	63	8		
Blaes	23	6		
ARDEN or No. 5 LIMESTONE	2	2		
Limy blaes	33	2		
Strata	172	0		
White ganister	9	6		
Strata	5	8		
IRONSTONE	0	3½		
Shale	1	2		
COAL	1	5		
Strata	34	2	364	8
COAL	0	7½		
Fakes	3	6		
COAL	0	2		
Fakes	4	9		
Sandstone	79	4		
Blaes	18	11		
INDEX or No. 4 LIMESTONE	3	11		
	592	8		

* The thicknesses given in this section are less than those actually cut in the shaft, a deduction of about an eighteenth having been made as an allowance for dip.

It will be seen from the above sections that the strata are somewhat thicker at Cowden and New Mills than at Newtongrange, and that they include four limestones, one of which, only 4 in. thick, perhaps corresponds to the Extra Limestone which is so commonly found on the west side of the basin. The thick sandstone that comes above the Index or No. 4 Limestone no doubt represents the Joppa Sandstone. It is also well developed in the Emily Pit, where it is about 89 ft. in thickness and overlain by a splint coal, 19 in. thick.

Limestone No. 4 is only seen at the surface in one place in this district, in the Gore Water a little above the bridge at Gorebridge, where the top is characterised by many specimens of *Productus latissimus*. In the Emily shaft, nearly a mile farther north-east, this limestone is about 3 ft. 9 in. thick and about 146 ft. above the Great Seam. The shaft pierces about 187 ft. of rock with no calcareous band above this limestone.

In the Gore Water almost due north of Harvieston Mains there is a parrot shale, at least a foot thick, which must lie between Limestones No. 4 and 5. It was formerly worked to a considerable extent, chiefly from the old Gore Pit, and is said to have been a first-class gas producer, but to have yielded no coke.

A short distance above the thick sandstone, on the horizon of the Joppa Sandstone, in the old Cowden Cleugh Quarry, a little more than a mile and a half E.N.E. of Dalkeith Station, there are two thin coals 10 or 12 ft. apart. Parrot occurs in both, but that in the lower appears of better quality and is in places as much as 10 in. thick. The lower coal may be on the horizon of the parrot shale which was formerly worked near Gorebridge, and it may also represent the South Parrot of the west side of the basin. The coals, recorded as splint, which come just above the Joppa Sandstone in the Cowden and Emily Pit sections, also appear to be near this horizon.

In the strip of wood extending west of the Cowden Cleugh Quarry, rock consisting largely of sandstone is exposed as far as the probable position of Limestone No. 6, and calcareous sandstone is seen on both sides of the roadway near the probable horizon of Limestone No. 5. The latter band is visible in Gore Water at the old bridge 550 yds. above the footbridge, and again at the side of the stream a little farther up. The section in the burn is somewhat as shown below, beginning at the top :—

	Ft.	In.
LIMESTONE, the lower part more impure than the top, with occasional remains of *Productus latissimus*	9	0
Calcareous shale	3	0
Sandy LIMESTONE with *Cauda-galli*	3	0

Higher up the stream section about 18 ft. of shale and some lenticular seams of blue limestone, about 6 in. thick, with *Productus latissimus* and other fossils, appear beneath this limestone.

Limestone No. 6 is seen twice in the South Esk, one locality being three-quarters of a mile above the foot of Gore Water, and the other a quarter of a mile from the same point. It contains broken fragments of crinoids, weathers with a yellow crust, and is perhaps as much as 6 ft. thick, but the lower portion is impure.

C. T. C., C. B. C.

CARBERRY AND PRESTONGRANGE.

Limestone No. 4 has been cut through in the shafts at Carberry, where it is 129 ft. above the Great Seam. Both No. 4 and No. 5 have been met with at Wallyford, where the section is as follows:—

	Ft.	In.
Shale	3	6
LIMESTONE (No. 5)	1	9
Sandstone and shale	93	2½
FOUL PARROT COAL	0	6
Sandstone and shale	56	5
Sandstone	33	10
Sandstone and shale	17	0
Fireclay	3	3
Sandstone bands	9	4
Shale mixed with coal	1	9
Sandstone and shale	11	8
LIMESTONE	0	4
Sandstone and shale	11	11
Sandstone	101	2
Sandstone and shale	14	2
Fireclay	2	4
LIMESTONE (No. 4)	1	6
	363	7½

The limestone, 4 in. thick, in the above table probably corresponds to what has been elsewhere named the Extra Limestone. It will be noticed that the thickness of the strata between No. 4 and No. 5 Limestones is considerably less here than at Cowden.

Limestones No. 4, 5 and 6 all crop out on the shore between Prestonpans and the Mid-Lothian county boundary. A good part of the intermediate strata is also shown, but the section is somewhat obscured by faults. The sequence of beds above and below No. 4 Limestone is given in the subjoined table:—

		Ft.	In.
	Shale with ironstone ribs	11	0
	Sandstone	30	0
	Sandstone and shale	42	0
	Blue shale with sandstone and ironstone layers	19	0
	Sandy fireclay	3	0
	Sandstone and shale	20	0
	Sandy shale with plant remains ..0 ft. to	6	0
	Sandstone and shale	26	0
	False-bedded sandstone	105	0
	Shale	(?)10	0
LIMESTONE No. 4.	LIMESTONE, compact	1	5
	Shale parting	0	3
	Earthy LIMESTONE, with *Productus latissimus*	0	9
	Sandstone	10	0
	Sandstone and shale	2	0
	Blue shale with sandstone and ironstone layers	4	0
		290	5

Limestone No. 4 crops out at the west end of Prestonpans, where it is rich in fossils and is overlain, as usual, by a thick sandstone.

Limestone No. 5 is split up into three parts by beds of shale, which, like the limestone itself, are extremely fossiliferous. The lowest part, full of *Productus latissimus*, is an irregular bed, seen only at very low water. Limestone No. 6 occurs on the shore opposite Drummore, and is succeeded by a series of more or less clayey sandstones, now included with the Roslin Sandstone series (Millstone Grit). E. M. A.

CHAPTER XII.

THE ROSLIN SANDSTONE SERIES (MILLSTONE GRIT) OF THE MID-LOTHIAN BASIN.

This series includes, as already indicated, all the strata that lie between the No. 6 or Castlecary Limestone and the fireclay seat below the first coal of fairly good quality, at the base of the Coal Measures. When the Mid-Lothian Coal-field was first mapped by the Geological Survey, the base line of the Millstone Grit was drawn at the top of No. 6 Limestone at Portobello and Gilmerton, but, in other localities, it was placed at a higher level to exclude a thick mass of shales. But, notwithstanding the inclusion of these shales, the characteristic feature of this division is the occurrence in it of a succession of coarse, pebbly, often reddish grits* and sandstones with fireclay. The series is remarkably destitute of coals of good quality, though rich in fireclay.

During the revision the upper limit of the division was generally defined in accordance with the method adopted in the original survey. In each locality where the exposures are clear, the boundary line is of a fairly definite character, but it is uncertain whether it always occupies the same stratigraphical horizon.

On the basis of the plants collected by Mr. Tait from the members of this series, Dr. Kidston has recognised an important palæontological break in the lower portion, which has led him to modify his classification of the Carboniferous strata (see p. 50). The break is not of an absolutely definite character, for *Lepidodendron veltheimianum*, which was hitherto supposed to be confined to Lower Carboniferous rocks in this country, has now been found at Levenhall in beds which are regarded as Upper Carboniferous. And in a somewhat similar manner *Lepidodendron glincanum* (Eichwald) has been found in the South Esk near Carrington Barns, in a bed which may likewise be of Upper Carboniferous age. Dr. Kidston regards these two species of *Lepidodendron* as "wanderers," or species which have survived longer in this area than the other Lower Carboniferous plants. It is perhaps surprising that such instances have not been of more common occurrence when it is borne in mind that no stratigraphical evidence of unconformity has been detected in the series, and that the beds on either side of the break are of much the same lithological character.

Dr. Traquair has also examined the fish remains which have been collected from this division, and the evidence thus obtained supports, so far as it goes, Dr. Kidston's conclusions.

The detailed mapping seems to show that the palæontological

* Mr. J. G. Goodchild ("Desert Conditions in Britain," *Trans. Geol. Soc. Glasg.*, 1897, vol. xi. p. 71), refers the red colour of the Roslin Sandstones, and of various other Carboniferous rocks, including the Red Measures of Fife, to infiltrations of ferric oxide received from New Red Rocks which he supposes to have formerly overlain them.

break occurs near a marine horizon, found by Mr. Tait, composed generally of one or two beds of nodular ironstone or limestone, which, at Joppa, is 235 ft. above Limestone No. 6, while in the South Esk its distance from the latter horizon varies from 150 to 232 ft. Other marine zones have been found by Mr. Tait in the Roslin Sandstone series, most of them in the lower portion. The only marine forms obtained by him from the upper portion are *Lingula mytiloides* and *Productus semireticulatus*. On the other hand, remains of land plants occur in greater numbers in the upper portion than in the lower.

On the western side of the basin an excellent section of the strata is exposed on the shore opposite Joppa Salt Pans, where they dip east or slightly south of east at angles of more than 50°. On the south side of the Sherriffhall fault they strike along the valley of the North Esk by Lasswade to Hawthornden and Roslin, where the massive coarse red sandstones in the upper portion of the series are almost horizontal and form picturesque cliffs on each side of the river. South-west of Roslin the series extends as far as Auchencorth Moss in a narrow synclinal belt, whose axial plane strikes north-east. Between Roslin and the South Esk near Carrington there are no good exposures, and it is probable that part of the series is here cut out by the Vogrie fault.

Along the east side of the basin the beds are laid bare in the South Esk near Carrington, the foot of the Gore Water, near Dalhousie Castle, and on the shore at Levenhall. In some localities the marine horizons are represented by limestone and in others by ironstone, and it is possible that in these cases the ironstone is of secondary origin and has replaced limestone, but, after a microscopic examination of various specimens, Mr. Howe considers that there is not sufficient evidence to prove this supposition.

C. T. C., W. G.

PORTOBELLO AND NIDDRIE AREA.

The rock ledges visible at low water at Joppa afford an almost complete section of this series (see Plate VII.), which is there composed of strata barren of coal seams but rich in clays and marls, the whole amounting to 740 ft. in thickness. The presence of ironstones containing marine fossils shows that the conditions of deposition resembled those that prevailed at intervals during the Carboniferous Limestone period, while the presence of fireclays with rootlets indicates conditions similar to those that recurred frequently during the formation of the Coal Measures.

The highest bed yielding Lower Carboniferous plants (Plant Bed No. 1 in Plate VII.) consists of a band, two or three inches thick, of shale and coal mixed, which lies at a distance of 43 yds. west from the westernmost corner of the Salt Pans. It is followed by a succession of strata including three beds of nodular ironstone containing marine fossils associated with fireclay and marl. The lateral shift of the Plant Bed by two faults crossing the strike at a considerable angle, is here very marked and affords an excellent example of the horizontal displacement of highly inclined strata by a fault. Index Plant Bed No. 2, from which Upper Carboniferous plants have been obtained, consists of a thin band of white cementstone lying in black

shales. The massive sandstones are limited to two in number. The lowest and coarsest, about 150 ft. thick, lies below the lowest beds of ironstone with marine fossils. It is somewhat flaggy at the top, but is conglomeratic towards the lower portion, pebbles of white quartz being rather abundant. The upper horizon of sandstone underlies the Seven-foot Coal and is about 100 ft. thick. It is of a reddish colour in the upper part and extremely false-bedded.

The Roslin Sandstone series is also exposed in Brunstane Burn, to the north of the viaduct, but, as the beds dip at a high angle and the stream runs nearly along the strike, not much of the sequence can be made out.

The lower portion of the series is also seen in the Niddrie railway cutting, where a marine limestone, 3 ft. 6 in. in thickness, is exposed at a distance of about 23 ft. above the Castlecary (No. 6) Limestone. W. G.

GILMERTON AND ROSLIN AREA.

The members of the series exposed in the North Esk between Elginhaugh and the big loop south of Roslin Castle are for the most part inclined at gentle angles. They all appear to belong to the upper portion, as remains of Upper Carboniferous plants have been found by Mr. Tait in the following localities: on the west bank of the Esk a third of a mile S.S.W. of Melville Castle, on the east bank between 660 and 730 yds. S.S.W. of Melville Castle, 100 yds. and 50 yds. below Lasswade viaduct, and a quarter of a mile south of Polton Station.

In the lower part of Bilston Burn about 280 ft. of beds at the base of the Roslin Sandstone are laid bare with an E.S.E. dip, at angles varying between 80° and 34°. More than half of them are composed of yellow or reddish sandstone, intermixed with shales and bands of fireclay. About 25 ft. above the base is a dark grey marine limestone (Roman cement), and about 107 ft. above that horizon is a two-inch coal with shale containing marine fossils.

Section of the Portion of the Roslin Sandstone Series Exposed in Bilston Burn.

	Ft.	In.
Shaly fireclay, mottled	4	0
Sandy fireclay	5	0
Sandstone	11	2
Gap	8	10
Sandstone	8	7
Gap	10	0
Sandstone	2	2
Blaes	4	9
Sandstone	2	4
Fakes	0	9
Sandstone	4	0
Fireclay, red and mottled	3	0
Sandstone, yellow, with red parts	14	0
Gap	32	0
Shale with rusty sandstone ribs	5	4
Hard sandstone rib	0	8

	Ft.	In.
Blaes with ironstone nodules	11	6
Coal, impure, with *Lepidodendron*	1	0
Fireclay, sandy, nodular	4	2
Fakes, sandy, with plies	9	10
Hard sandy rib	0	6
Sandstone	3	4
Clay, red	0	6
Fireclay	6	7
Coaly shale	1	0
Fireclay	10	4
Hard sandstone (forming cascade)	2	10
Gap	12	0
Shale	3	9
Ironstone rib	0	3
Shale with marine fossils	2	10
Coal	0	5
Fireclay	0	6
Gap	10	0
Sandstone	7	6
Fireclay and sandstone	5	0
Blaes	10	0
Red slaty ironstone	0	3
Clay shale, pale grey and red, with plants	0	3
Mottled red, white and yellow sandstone	2	0
Massive yellow sandstone, pebbly	29	0
Gap	4	0
Fireclay, rather pale grey	8	0
Bastard ironstone	0	6
Blaes	0	4
Ironstone rib with shells	0	3
Blaes	1	4
Calcareous blaes	0	8
Dark grey shaly limestone *	1	8
Dark grey clay shale	0	6
Gap	1	0
Fireclay	0	3
Coal, slaty	0	3
Pale grey clay shale with scattered hard yellow-weathering nodules, calcareous, increasing in numbers towards the base	5	6
Hard rib, clayey matrix, with many close hard yellow-weathering nodules, slightly calcareous, with some fossils	1	6
Blaes	0	3
Gap	1	4
Sandstone	3	0
Sandstone with some fakes	9	6
Coarse pebbly rib with clay galls and pyrites	0	3
Sandstone	2	0

Castlecary or No. 6 limestone.

In the upper portion of the series thin conglomerates often occur, showing a rather coarse matrix of yellow sandstone and many fragments of pale grey clay, dark grey shale, coal and parrot shale, together with occasional pieces of hard siliceous sandstone or ganister. Most of these ingredients vary in length between $\frac{1}{4}$ in. and 3 in., and are rather angular in outline. Large fragments of vein quartz, such as frequently characterise the coarser-grained sandstone bands, are not conspicuous. These conglomerates are sometimes 2 or 3 ft. thick, and display indications of erosion or of local unconformity at their base, the edges of some of the lower beds having been denuded

* See note at the end of this chapter.

before the overlying conglomerate was deposited. But similar instances of local unconformity are common throughout the series even where no conglomerate is seen. The individual beds of conglomerate cannot usually be traced more than a few yards. Good examples can be seen on the east bank of the Esk about 660 yds. S.S.W. of Melville Castle, and again on the south side of the river, 150 yds. north of Polton House. In the former locality two bands of conglomerate are exposed, one 3 ft. above the other, and in the latter locality there are also two, one 10 ft. above the other, with unusually large pieces of coal—one more than a foot long and 6 in. thick. The bands often contain large pieces of *Calamites* which seem authigenic. They do not appear to have been rolled or derived from a pre-existing bed.

It might be supposed that the conglomerates occur near and in connection with the palæontological break, but from the information provided by a bore which has been put down about 70 yds. W.S.W. of the south lodge of Melville Castle, it would appear that all the conglomerates observed must be nearer the top than the bottom of the series. About 200 yds. west of Hawthornden Castle conglomerates are to be found with pieces of pale grey clay, as much as 3 in. long (but without any coal or dark grey shale), which are probably not more than 150 ft. below the top of the series.

Between Roslin Castle and the eastern entrance to the Powder Mills, two faults are seen, and there is probably a third. One of these, with a north-west strike, crosses the big loop south of the Castle, and throws down the top of the series to the south-west, perhaps 40 ft. Another, with a similar strike, but hading in the opposite direction, makes a distinct break on the south bank of the river a quarter of a mile slightly south of west of the Castle. It is not accompanied with much crushing, but the amount of throw is not known. A third fault is inferred, because the top sandstone of the series is only a few feet above the Esk in the most southern portion of the big loop south of the Castle, while, in a locality less than a quarter of a mile farther north-west, we find beds of sandstone and shale which are probably less than 200 ft. above the Castlecary (No. 6) Limestone. The rock in the area between these two localities is not well seen, but it shows no indication of a steep dip such as would be required to bring in all the middle portion of the Roslin Sandstone series. In the workings in the Edge Coal group a little north-west of Roslin village, a fault has been proved striking N.N.W., and with a downthrow to the east of 168 ft., which is supposed to be a continuation of a dislocation crossing the Esk near the Carpet Works.

All the strata between the Carpet Works and the exposure of the Castlecary (No. 6) Limestone, rather more than a third of a mile slightly west of south of Oatslie, probably belong to the lower portion of the Roslin Sandstone series. A coarse massive sandstone, at least 60 ft. thick, is well seen on the east bank of the Esk, a third of a mile south-east of Oatslie, where it appears to be resting with a very uneven base in denuded hollows of the underlying fireclay. A little below the sandstone, but on the other side of the river, a coal 8 in. thick is seen. Some hard calcareous flaggy sandstones on the same

horizon as those which, in the South Esk, lie between 100 and 170 ft. above Limestone No. 6, crop out below the coal, and a little below these calcareous strata another coal about 6 in. thick is exposed. The remains of the following plants have been found in beds not far below the thick sandstone:—

Lepidodendron rhodeanum *Stern C.*
„ veltheimianum *Stern C.*
Calamites, several sp.

The beds in this locality are nearly flat, and the outcrops of Limestone No. 6 and the lowest coal are almost on the same level, from which it may be inferred that these two outcrops are separated by a fault with a downthrow to the north-east. Perhaps this dislocation is a continuation or branch of the Vogrie fault which skirts the southern margin of the coal basin.

C. T. C., J. S. G. W.

PENICUIK AREA.

The northern portion of the area of Roslin Sandstone, which lies to the south of Penicuik, occupies one of the minor troughs due to the system of shallow folds into which the strata in this part of the district have been thrown.

The northern end of this syncline is cut off by an E.S.E. and N.W. fault, which crosses the river Esk at the Valleyfield Paper Mills and has been proved in several bores in the ground farther to the east and west. The fault has a downthrow to south and brings the sandstones against the rocks of the Upper Limestone group in the river.

The western boundary of the sandstone is also shifted a few hundred yards to the south by the fault which crosses the Esk and the Hare Burn.

A good section of the sandstones is exposed in the steep southern bank of the Esk in South Bank Wood, where thick-bedded white, grey and reddish gritty sandstones and pebbly bands, with intercalations of thin flakes and purplish sandy shales, dip east at 15° to 20°. A short distance lower down in the series there is a curious bed of fragmental rock made up of angular stones derived from volcanic material, in a sandy matrix. A similar rock is found in the Hare Burn, associated with pebbly grits and friable yellow sandstones.

The journal of a bore put down through the Roslin Sandstone at a point in the Hare Burn, exactly one mile above Hare Burn Bridge, gives 79 fms. of sandstones and flakes above the highest limestone (No. 6), with a 1-ft. seam of foul coal at 53 fms.

L. W. H.

CARRINGTON, NEWTONGRANGE AND SMEATON AREA.

Excellent sections occur in the lower part of the series in the South Esk, for a quarter of a mile below, and about a mile above, the junction with Gore Water, but some of the beds are very inconstant in thickness. Rather more than a third of a mile south of the junction of the Esk and the Gore Water, a W.N.W. fault, which has a considerable downthrow to the south, crosses the Esk at Shank, but the beds

on either side of the fault cannot be correlated with confidence. The sections on both sides are given below, in descending order:—

Section in the South Esk on the North Side of the Shank Fault.

	Ft.	In.
Flaggy sandstone	1	0
Mottled red and buff impure clay with rootlets	3	0
Hard irony sandstone	0	6
Mottled red and yellow sandy clay	0	9
Soft flaggy red and yellow sandstone	2	3
Massive soft yellow sandstone	18	0
Gap	9	0
Fireclay, pale grey	2	0
Purple and red shale with fish remains at the base	2	0
Fireclay	0	6
Red and yellow flaggy sandstone with rootlets	1	9
Sandy nodular clay, pale grey and red, with rootlets	3	0
Flaggy yellow sandstone with rootlets and many Upper Carboniferous plant remains	1	8
Purple or greenish shale with fish remains in the lower part	5	4
Soft yellow false-bedded massive sandstone with remains of tree stems	72	6
Purple-red shale	1	0
Gap	9	0
Nodular red and yellow LIMESTONE with corals and other fossils	2	0
Mottled red and yellow fireclay	13	0
Soft yellow sandstone	2	6
Soft mottled sandstone, red, yellow, lilac, etc.	49	6
Flaggy sandstones and sandy clays	13	0
Dark grey shales and thin flaggy hard calcareous sandstones	12	0
Coal streak	0	0⅛
Pale grey fireclay	5	0
Massive soft yellow sandstone	7	6
Dark grey shale	0	6
Pale grey fireclay	2	0
Gap	10	0
Massive yellow sandstone	8	0
Dark grey shale	7	0
Gap	20	0
Pale grey fireclay	2	0
Soft massive sandstone, yellow, purple or white	45	0
Dark grey shale with some thin ironstone courses	35	0
CASTLECARY or No. 6 LIMESTONE.		
	367	3⅛

The remains of Upper Carboniferous plants and fishes which were collected from a flaggy sandstone and a purple shale near the top, are as follows:—

Pleuroplax attheyi (*Barkas*).
„ rankinei (*H. & A.*).
Rhadinichthys monensis (*Egerton*).
Lepidodendron obovatum *Sternb.*
„ aculeatum *Sternb.*
Cf. Sigillaria sillimanni *Brongt.*
Clathrate Sigillaria or Lepidophloios.
Lepidostrobus.

Section in the South Esk on the South Side of the Shank Fault.

	Ft.	In.
Sandstone.		
Shale	(?) 2	0
Flaggy sandstone	6	0
Dark grey shale, basal part with *Lepidodendron glincanum*	16	0
Purple and dark grey shale	5	0
Grey and buff fireclay	4	0
Massive yellow and red sandstone	19	0
Gap	2	6
Pale grey fireclay	2	6
Brown and yellow massive sandstone	42	0
Pale grey and red mottled fireclay	16	0
Red calcareous impure ironstone with sphærosiderite	2	0
Mottled yellow and red fireclay	8	6
Massive soft white and deep red false-bedded sandstone	62	0
Flaggy purple and grey sandstone	1	0
Yellow and red sandstone	3	0
Gap, including supposed position of a marine ironstone visible in an adjoining section farther south *	10	0
Yellow and white sandstone	2	0
Pale grey fireclay	5	0
Gap	24	6
Yellow sandstone	1	0
Pale grey fireclay	1	0
Yellow sandstone	5	0
Dark purple shale	5	0
Calcareous hard flaggy sandstone	0	6
Shale	4	0
Black carbonaceous shale or smut	0	4
Purple and pale grey shale and shaly fireclay	10	0
Yellow sandstone	1	0
Gap	43	0
Calcareous sandstone with Orthotetid shell	3	6
Shale	2	0
Calcareous sandstone with Orthotetid shell	1	6
Shale	39	0
CASTLECARY or No. 6 LIMESTONE.		

The shale which contains *Lepidodendron glincanum* contains also—

Calamites ramifer *Kidston.*
Lepidostrobus variabilis *L. & H.*
Lepidodendron gaudryi Renault.
Lepidophloios.
Stigmaria ficoides *Brongt.*
Productus sp.
Cf. Anthracomya valenciensis *R. Eth., Jun.*
Rhizodopsis sp.

The estimated interval—232 ft.—between Limestone No. 6 and the higher marine limestone in the first section is greater than that between Limestone No. 6 and the supposed position of the marine shale and ironstone in the second section, which is estimated at 150 ft.

The higher limestone has only been seen in one place, and the ironstone does not occur in all the localities where it might naturally be expected, but these two beds may probably be on the same horizon. On the N.N.E. side of the fault, the interval between the marine limestone referred to and the plant bed with Upper Carboniferous forms is about 89 ft., while on the S.S.W. side the interval between the ironstone and the plant bed which contains *Lepidodendron glincanum* is about 177 ft.

* See note at the end of this chapter.

If we consider merely the relations of the plant beds to Limestone No. 6 without correlating the marine limestone and ironstone, we find that the bed that contains the undoubted Upper Carboniferous assemblage is about 322 ft. above this limestone, while the band with *Lepidodendron glincanum* is 326 ft. above that horizon.

At the top of the Lady Victoria shaft, Newtongrange, a thickness of about 110 ft. of the lower part of the series is passed through, about half of which consists of shale. A coal, 7 in. thick, is pierced about 95 ft. above Limestone No. 6, and probably corresponds to one of the coal smuts in the South Esk.

In the railway cutting a third of a mile south-east of Smeaton Station, various beds which seem to belong to this series are exposed on the south side of a sandstone quarry, but it is probable that a fault passes in a nearly east and west direction between the quarry and the cutting. Among the beds in the cutting we find an impure limestone, 3 ft. thick, containing crinoids and *Alveolites depressa*, which is considered to be on the same horizon as the marine limestone in the South Esk, and the equivalent of the lowest of the calcareous horizons—which also contains *Alveolites depressa*—in the Roslin Sandstone series on the east side of Port Seton harbour (one-inch map 33). Just below this limestone there is a grey shale, and about 70 ft. farther down comes a similar bed containing calcareous nodules and marine fossils, which is underlain by a coal about a foot thick. C. T. C.

MUSSELBURGH AREA.

On the shore at Musselburgh the low angle of dip and the false-bedded character of the sandstones do not permit accurate or detailed measurements, but the following approximate thicknesses may be given. The Six-foot Coal is underlain by false-bedded sandstones and shales about 100 ft. thick, and these in turn by about 25 ft. of shales with an ironstone band containing marine fossils, while at the base an impure coal yields plants of Upper Carboniferous age. Descending in the series, we find next in order a coarse grit, about 100 ft. thick, forming Westpans Rocks, which contains near the summit a specimen of *Lepidodendron veltheimianum*, visible at low water. The grit is underlain by shales and thin grits perhaps about 60 ft. thick. At the top the marly shales are mottled and contain marine fossils, and near the base a shale yields plants (Plant Bed No. 1 in 6-in. Sheet Edin. 4 N.W.) of Lower Carboniferous species. A little distance above this plant zone a limestone band contains numerous marine fossils.

At the east side of Westpans Rocks there are some interesting cases of false-bedding in thin lenticular sandy shales, in which the more sandy laminæ are arranged in a succession of minute sharp curves with axial planes lying at gentle angles to the horizon and nearly parallel to one another. In some beds the minor laminæ are also crossed by a number of parallel planes, along which there seems evidence of slight displacement, and which are almost parallel to the axial planes of the curves alluded to. It might be suggested that the minor laminæ are here crossed by a set of cleavage planes or strain slips, and that they are probably parallel to some obscure

thrust planes. But no planes of movement have been detected in the neighbourhood, and there is no perceptible crushing or shearing in the rocks. It is obvious that the curves and planes of displacement were formed before the overlying rocks were deposited, and before the beds affected were consolidated. Perhaps a series of sliding motions or "creeps" down a gentle slope may have caused certain beds to be folded and broken while they were still in a soft condition. C. T. C., W. G.

NOTE ON THE LAMELLIBRANCH FAUNA FROM THE MILLSTONE GRIT.

The beds marked with an asterisk on pp. 247 and 251 yielded to Mr. Tait the remarkable assemblage of lamellibranchs referred to on pp. 52 and 53, Chapter VI.

CHAPTER XIII.

THE COAL MEASURES OF THE MID-LOTHIAN BASIN.

In the south part of the Mid-Lothian basin the base of the Coal Measures is drawn below the fireclay seat of the Jenny Meggat Coal, which is the first seam above the barren Roslin Sandstones. In the north part, it is also drawn below the seat of the first coal overlying the Millstone Grit, which, in the neighbourhood of Joppa, is the Seven-foot Coal, and near Cowpits, the Six-foot Seam.

Near Hawthornden the Jenny Meggat Coal is about 130 ft. below the Parrot Rough seam, and, one or two feet above the latter horizon, a band of shale and ironstone charged with the lamellibranch, *Carbonicola robusta*, has been detected in some localities, but not as yet at Whitehill. This band was lately found by Mr. Gibson, but it was known to the late Mr. James Bennie of the Geological Survey many years ago. A similar fossiliferous band occurs above the Fifteen-foot Coal of Joppa, and has been found by Mr. Tait above the same coal in the New Craighall Pit* and also above the lowest coal in the little basin of Coal Measures at Port Seton. It is also stated by Mr. Milne† that a band of fossil shells occurs above the Three-foot Coal of Cowpits. In all these places the bands are believed to be on the same geological horizon, though the intervals that separate this horizon from the line mapped as the top of the Roslin Sandstone series vary greatly in thickness.‡

This variation is shown by the following tabular statement:—

	Ft.
Supposed approximate distance at Brunstane, Joppa	215
" " " in a "crosscut" at New Craighall	171
" " " on Joppa shore	150
" " " at Whitehill	136
" " " at Port Seton	38
" " " at Cowpits	30

At Brunstane and on Joppa shore three thick coals occur in the interval, at Cowpits two, at Port Seton only one, about a foot thick, but it is noteworthy that the last of these contains a seam of Parrot,

* *Op. cit.* p. 18.

† Dr. Wheelton Hind has examined the specimens from this pit and finds both *Carbonicola robusta* and *C. acuta*.

‡ Since the above paragraph was written, Mr. R. Martin, formerly Manager of Niddrie Colliery, has inferred from recent mining exploration that the Three-foot Coal of Cowpits corresponds to the Nine-foot of New Craighall, not the Fifteen-foot. At New Craighall the Nine-foot Seam is 18 or 19 ft. above the Fifteen-foot. Should Mr. Martin's correlation be definitely established, it would seem possible that Mr. Milne's information was incorrect, and that the band of fossil shells referred to by him occurred above the Six-foot Coal of Cowpits, not the Three-foot. At Cowpits the Six-foot Seam is only $\frac{9}{8}$ ft. below the Three-foot.

like the Parrot Rough Coal of Whitehill and Polton. The great thickness at Brunstane seems largely due to the presence of a thick red sandstone, 100 ft. thick, which lies immediately below the Fifteen-foot Coal.

The Coal Measures of this district may be conveniently divided into two groups. The upper one, amounting to 500 or 600 ft. in thickness, contains no workable coals, and probably corresponds to the Red Measures of Fifeshire, which have been correlated with the Middle Coal Measures of England. Its base line has been drawn in the Dalkeith district at the top of a marine bed, to be subsequently described. These upper beds occupy an area, less than a square mile in extent, on the north side of the Sheriffhall fault, and in the central and northern parts of this area they generally dip south, so that the underlying measures emerge from below them a little above the junction of the North and South Esk.

It is probable that the lower part of the same barren beds recurs at the northern end of the coal basin near Musselburgh, but its outcrop here is entirely hidden beneath raised beach materials and drift.

The lower or coal-bearing group of the Coal Measures underlying these red barren strata may be arranged in two subdivisions: (1) an upper or Craighall set of coals, which do not occur on the south side of the Sheriffhall fault; (2) a lower set, which in the north-western part of the basin are often called the Brunstane Coals, and on the north-eastern side the Cowpits Coals. These two groups of coals are separated by about 200 ft. of strata, in which no thick coal, or only one—the Golden Coal *—appears to occur.

In the neighbourhood of Joppa and Craighall the total thickness of all the coals exceeding 23 in. in both these groups appears to be about 68 ft. It is believed, as already indicated, that the Fifteen-foot or Ell Coal of Joppa and Niddrie corresponds to the Parrot Rough of Whitehill, or perhaps to the Parrot Rough and Jewel combined. The Nine-foot may correspond to the Splint of Whitehill, and Salters to the Great Seam, but the last correlation is doubtful, as the Great Seam appears to be only from 1 to 15 in. thick at Elginhaugh and Eskbank. The total thickness of the lower seams, counting downwards from the top of the Great or Salters, is greater in the northern part of the basin than in the southern. In the New Craighall Colliery, Niddrie, in a crosscut from the Four-foot to Salters seam, the collective thickness of the Salters, Nine-foot, Fifteen-foot and Four-foot seams is estimated to be about 21 ft., and the total thickness of these together with the Seven-foot Coal is, in this locality, probably about 26 ft. In the Whitehill winding shaft the collective thickness of the Great Seam and the lower coals is about 18 ft., and there is probably a lower coal—the Jenny Meggat—about 18 in. thick.

Many coarse false-bedded grits occur within the Coal Measures, parts of which are often of a reddish colour and have a considerable resemblance to certain members of the Roslin Sandstone series. A bed of this character lies immediately below the Jewel Coal of

* Mr. Milne (*op. cit.*) places this coal about 40 ft. below the Jewel Seam, and gives its thickness at various places on the west side of the basin. In the new Woolmet pit it is 16 ft. below the Jewel Coal.

Whitehill—and thus not far above the top of the Roslin Sandstone—a second, often called the "Rough Coal post," just below the Great Seam, a third, which is well seen in the part of Dalhousie Burn below Cockpen Church, some distance above the Great Seam, and others in the still higher measures in Dalkeith Park.

A few thin bands of impure limestone have been found on different horizons, all of which are above the position of the Great Seam. Some of them are compact and slightly argillaceous, and are associated with red or purple shales, but one, which is taken as the top of the Lower Coal Measures, is partly of marine origin and contains remains of *Spirifer*.

The general lithological character of the grey shales differs to some extent from that of the shales in the underlying Edge Coal group, being rather less sandy and less micaceous. The sandstones in the Coal Measures, on the other hand, are perhaps as a rule rather less mixed with shaly material than the arenaceous beds in the Edge Coal group. These features are not, however, sufficiently persistent to be of much value by themselves for purposes of differentiation. It is by means of the fossil flora and fish fauna that these two coal-bearing divisions of the Carboniferous system can be distinguished with confidence. The mollusca are less numerous and do not always afford a decisive test (see p. 221). C. T. C., W. G.

I. Lower Coal Measures.

JOPPA, NEW CRAIGHALL, MUSSELBURGH AND WOOLMET FIELDS.

Most of the measures extending from the base of the group up to the Greymecham Coal are exposed on the shore at Joppa (see Plate VII.), but the coal outcrops are, as a rule, concealed under sand. The position of the Fifteen-foot Seam is determined by a band of ironstone nodules, containing large specimens of *Carbonicola robusta*, which has been found to overlie this horizon in many portions of the coal-field (see p. 254).

The seams all occur towards the middle of the basin, and are consequently much less inclined than those of the Edge Coal group. The following inclinations in the Ell (or Fifteen-foot) Coal occur in the New Craighall Collieries—on the 450 ft. (below Ordnance Datum) level, 25° to 32°; on the 600 ft. level, 14° to 22°; and on the 800 ft. level, 15°.

On the 450 ft. level the Ell Coal has the following composition :—

Ell Coal—New Craighall Collieries.

	Ft.	In.
Pelt	0	7
Coal	2	11
Fireclay	2	9
Coal	3	6

The following section gives the thicknesses of the coals at Joppa, as well as of the intermediate strata :—

Section of the Brunstane Coals at Joppa.

	Ft.	In.
Coal (Greymecham)	3	7
Sandstone	110	0
Coal	2	0
Fireclay (Salters)	4	0
Coal	2	0
Sandstone and shale	45	0
Fireclay	18	0
Coal	1	1
Fireclay (Nine-foot)	2	0
Coal	5	6
Shale	31	0
Coal, Fifteen-foot	12	6
Red sandstone	100	0
Fireclay	8	0
Sandstone and shale	15	6
Coal, Four-foot	4	0
Fireclay	6	0
Sandstone	3	0
Fireclay with ironstone	20	0
Sandstone	24	0
Coal	1	3
Fireclay (Seven-foot)	4	0
Coal	6	0
Fireclay	2	6
Coal	2	0
Fireclay	1	6
	434	5

It may be observed that the thicknesses of the coals, etc., given in the above section are considerably greater than those calculated from the information obtained respecting the beds in a cross cut mine, driven from the Four-foot Coal to the Salters Seam in the New Craighall Colliery, Niddrie, from which the following vertical section has been constructed:—

Section in the New Craighall Colliery, Niddrie.

	Ft.	In.
Fakes	0	0
Salters Coal	5	0
Fireclay	2	0
Blaes	6	6
Kingle, hard	1	3
Bastard fireclay	11	0
Sandstone, hard	1	3
Bastard fireclay	8	7
Blaes, fireclay and Coal	2	0
Nine-foot Coal	5	6
Fireclay, holing	1	8
Blaes	2	1
Faky sandstone	7	0
Blaes, "mussels" and balls (ironstone)	7	3
Fifteen-foot Coal	7	6
Fireclay, holing	1	8
Sandstone	2	10
Fireclay	1	8
Blaes	5	7
Carry forward	80	4

	Ft.	In.
Brought forward ..	80	4
Fakes	3	4
Sandstone	70	7
Blaes	4	6
FOUR-FOOT COAL	2	10
	161	7

The "mussels" referred to in this section consist of *Carbonicola robusta* and *Carbonicola acuta*, as already stated, and the following more detailed section, measured by Mr. Tait, shows more exactly the stratigraphical relations of the shale that contains them:—

Detailed Section in the New Craighall Colliery, Niddrie.

		Ft.	In.
NINE-FOOT COAL		5	6
Fireclay		1	0
White sandstone		9	0
Blaes or fireclay		0	10
Black shale with ironstone nodules with remains of *Carbonicola robusta* and *Carbonicola acuta*		3	0
Well-bedded blaes		4	9
COAL	FIFTEEN-FOOT COAL	2	3
IMPURE COAL		0	7
COAL		2	0
Fireclay		0	9
COAL		4	0
IRONSTONE		0	5
COAL		0	7

According to Dr. Hind, the specimens of *Carbonicola robusta*, referred to in the foregoing section, belong to a variety, previously figured by him,* found at Shotts and at Dalmellington.

The section in the Woolmet shaft—a quarter of a mile east of Woolmet House—is of considerable importance since it supplies details of the strata intervening between the Brunstane or lower group and the Craighall or upper group of coals. It also shows that the Cowpits succession can now be recognised on the western side of the basin. An abstract of the section communicated by Mr. R. Martin is given below in descending order:—

	Ft.	In.
Fireclay and sandstone	27	6
DIAMOND COAL, variable, but averages	4	0
Fireclay	7	0
COAL	1	0
Various strata	26	6
JEWEL COAL (waste)	3	6
Fireclay	16	0
GOLDEN COAL †	2	6
Carry forward ..	88	0

* "A Monograph on Carbonicola, Anthracomya and Naiadites," *Monograph of the Palæontographical Society*, 1894–96, plate ii. figs. 3–6. The specimens figured are said by Dr. Peach to have come from two horizons, one near the Slaty-band Ironstone, at the base of the Coal Measures, and another near the Kiltongue Coal, more than 400 ft. above the base of the Coal Measures.

† Probably so named from the abundant admixture with iron pyrites. See R. Bald's "Observations on the Coal-Field and accompanying Strata in the Vicinity of Dalkeith, Mid-Lothian," *Edin. Phil. Jour.*, 1827, vol. iv. p. 115.

	Ft.	In.
Brought forward ..	88	0
Fireclay	5	0
Coal	2	6
Fireclay	12	0
Sandstone..	24	0
Coal	2	0
Various strata	67	0
Coal	1	6
Fireclay	6	0
Coal	0	6
Various strata	9	0
Coal	1	8
Various strata	8	4
Sandstone..	39	6
Cowpits Little Splint Coal	2	6
Various strata	22	0
Coal	0	6
Fireclay	2	0
Sandstone..	81	6
Coal	0	3
Fireclay	3	0
Coal	1	0
Pelt	0	3
Fireclay and blaes	2	1
Cowpits Five-foot Coal	4	11
Fireclay	0	6
Grey sandstone	5	7
Blaes	5	0
Quarry Coal	1	9
Strata	144	2
Glass or Greymecham Coal	2	0
Strata	64	0
Barrs or Salters Coal	4	0
Strata	43	0
Nine-foot Seam	5	0
	662	0

The thicknesses of the upper group of coals, etc., at Craighall are given in the subjoined table:—

	Ft.	In.
Clayknowes Coal	3	0
Sandstone and shale	28	0
Coal	1	6
Sandstone and shale	135	0
Sandstone (red and white)	135	0
Shale	4	0
Coal (the Splint)	5	0
Sandstone and shale	45	0
Ironstone	0	0½
Sandstone..	18	0
Coal (the Rough)	4	0
Shale	42	0
Sandstone and shale	13	0
Coal (the Beefie)	6	0
Sandstone..	36	9
Grey bands	16	0
Shale (red)	30	0
Sandstone (red and white)	22	0
Shale	28	0
Coal (the Diamond)	6	0
Sandstone and shale	20	0
Coal (the Jewel)	3	0
	601	3½

The shale bed above the Splint seam is said to contain a bed of mussels (probably *Carbonicola*).

At Olive Bank, Musselburgh, the Splint Seam of Craighall occurs at a depth of about 615 ft. below the surface, and is overlain by 529 ft. of solid rocks. The journal of one of two adjacent borings shows a mussel (presumably *Carbonicola*) rib, an inch thick, immediately above this coal, but no such rib appears to have been found in the workings. In the journal of No. 1 Bore two thin beds of kingle are recorded, the top band being 210 ft. beneath the surface and another nearly 4 ft. below this band. It seems possible that these kingle beds correspond to the impure marine limestone which has been taken as the top of the Lower Coal Measures at Dalkeith, though the journal shows no coals near them which might correspond to the two coals beneath the impure limestone referred to. The top coal shown in the journal is 401 ft. beneath the surface, and only an inch thick. About 3 ft. farther down there is a dirty coal, 2 ft. 8 in. thick. W. G., E. B. B.

SMEATON, COWPITS AND PINKIE FIELDS.

At Cowpits, on the east side of the Coal Basin, the section is reported to be as shown below in descending order :—

	Ft.	In.
Coal, Little Splint	2	2
Sandstone and shale	8	0
Coal	1	4
Sandstone and shale	1	1
Coal	0	6
Sandstone and shale	92	4
Coal, Five-foot	5	6
Shale with sandstone	5	5
Coal, Quarry	1	6
Sandstone	138	0
Coal, Glass	2	0
Sandstone and shale	48	0
Coal, Barrs	4	0
Sandstone and shale	24	0
Coal, Three-foot	3	0
Shale	9	0
Coal, Six-feet	4	6
Fireclay	12	0
	362	4

It may be noted that Mr. David Milne * states that remains of shells resembling *Unio* lie embedded in a stratum of shale which forms the roof of the Three-feet Coal, and there can be little doubt that these shells would now be placed in the genus *Carbonicola*.

As pointed out by Mr. R. Martin, a comparison of the above section with that of Woolmet Pit, p. 258, makes it probable that the Glass Coal corresponds to the Greymecham, Barrs Coal to Salters, and the Three-foot of Cowpits to the Nine-foot of New Craighall. E. B. B.

The Cowpits Coals rise to the surface at Musselburgh Links and Pinkie, and dip to the west at an angle of 10°. At the latter place they are intersected by two parallel east and west faults, the first

* *Op. cit.*, p. 18. See footnote on page 254 of this memoir.

with a downthrow of 5 fms. to the south and the other of 6 fms. to the north. South of the latter fracture the coals continue without interruption to Midfield where they are thrown down 7 fms. to the north by a W.N.W. fault. Half a mile farther south they are again intersected by a large fault with a downthrow to the south-west, which strikes nearly north-west and passes a little south of Carberry Tower. At Cowpits its amount of downthrow is said to be 16 fms., but it must increase eastwards as it shifts the base of the Coal Measures more than half a mile to the east. Hence we find near Carberry the basal beds of the Coal Measures in contact with the Upper Limestone group.

The Dean Pit was formerly in operation about a quarter of a mile west of Carberry Tower, and it is clear that the two seams—one measuring 3 ft. 6 in. and the other 5 ft.—which were there worked, belong to the Coal Measures. At least three outcrops of coals occur in the Dean a short distance south-west of the pit and north-east of Smeaton Station, and from a bed exposed in the Dean Mr. Tait has collected remains of fish scales which Dr. Traquair has named *Cœlacanthus elegans*, a fossil fish which has never been found below the Coal Measures.

The conclusion that the Dean Coals belong to the Coal Measures is confirmed by information provided by a bore, put down about 500 yds. north of Smeaton Farm, which pierced 440 ft. of strata with many coals without reaching the barren Roslin Sandstone series. Judging from the adjacent exposures the dip in the bore is not likely to be more than 15°, and on this supposition there is not space for this barren series to intervene between the probable outcrops of the beds found at the bottom of the bore and the Dean. Hence the coals in the Dean section cannot belong to the Upper Limestone group as was formerly supposed.

Close to Smeaton Station a soft coarse-grained sandstone is exposed which has considerable resemblance to some members of the Roslin Sandstone, but if it does belong to this series, a large fault with downthrow to north must occur between it and the Dean.

In the journal of a bore put down 330 yds. south-west of Smeaton Farm, a coal met at a depth of about 201 ft. is recorded as probably Barrs Coal. If this correlation be correct, then the coarse sandstone just referred to must be within the Roslin Sandstone series. But this correlation seems very doubtful. For in the burn, 150 yds. W.N.W. of Smeaton Farm, remains of ferns, including *Alethopteris decurrens* and *Neuropteris heterophylla*, have been obtained from a band of shale which there forms the roof of an eight-inch coal. Mr. Tait has not found *Alethopteris decurrens* anywhere else in Mid-Lothian so low down as this shale must be if the above correlation be correct. It was not found at Whitehill or Polton Collieries, but above the Splint Coal (of Craighall), in the Olive Bank sinking, and 170 yds. N.N.E. of Smeaton Lodge, in a bed on a considerably higher horizon than the shale referred to. It is interesting to notice also that, according to Dr. Kidston,* *Alethopteris decurrens* does not, like *A. lonchitica*, extend down into the Millstone Grit of England.

* "On the Various Divisions of British Carboniferous Rocks as Determined by their Fossil Flora," *Pres. Address, Roy. Phys. Soc. Edin.*, 1893, vol. xii. p. 244.

Rather more than 100 yds. south of the bore last mentioned an important fault was met in the Splint Seam in the old Smeaton Colliery, which formed the northern boundary of the workings. The direction is W.N.W., the downthrow is to the south and supposed to be large, but the exact amount is not known. It is uncertain where this fracture intersects the Esk. It may cross about 400 yds. north-east of the junction of the North and the South Esk, and continue thence to a fault proved near Newton House, in the centre of the basin, which has there a downthrow to the south of 6 fms. But a dislocation, hading to the south and with a considerable throw, certainly crosses the Esk at a point 600 yds. N.N.E. of the junction, and would, if prolonged in an easterly direction, come very near the fault proved in the workings.

The following section gives the thicknesses of the different beds at Smeaton and the adjoining district:—

Section of the Upper Group of Coals at Smeaton and Dalkeith.

	Ft.	In.
Coal (the Clayknowes)	3	6
Shale	8	0
Coal (soft)	1	0
Sandstone and shale	83	0
Coal	1	3
Red sandstone and shale	44	2
Shale with *Carbonicola* (?)	11	1
Coal (the Splint)	3	10
Sandstone and shale	24	8
Coal (the Rough)	0	6
Shale	5	8
Grey sandstone	84	4
Shale	0	10
Coal (the Beefie)	3	6
Shale and sandstone	7	9
Sandstone	19	6
Sandstone and shale	28	7
Coal (the Diamond)	0	10
Sandstone and shale	10	6
Shale	7	9
Coal (the Jewel)	4	0
Total thickness	354	3

If this section be compared with that of Craighall (see p. 259) it will be seen that the total thickness both of the intervening strata and of the coals is much less on the eastern side of the basin than on the west. The "Rough" and "Diamond" Coals, which are respectively 4 ft. and 6 ft. thick at Craighall, are not workable at Smeaton.

At Smeaton the bed of shale immediately above the Splint Coal is said to contain, as at Craighall and Olive Bank, a bed of "mussels" (probably *Carbonicola*). *Naiadites carinata* and *N. cf. modiolaris*, determined by Dr. Wheelton Hind, were collected from the waste heap of an old pit 760 yds. north of Cowdenfoot, said to have come from a little above the Jewel Coal. The following fish remains, named by Dr. Traquair, were obtained from the same heap:—

Pleuracanthus lævissimus *Ag.*
Gyracanthus formosus *Ag.*

Acanthodopsis wardi *H. & A.*
Megalichthys hibberti *Ag.*
Rhizodopsis sauroides (*Williamson*).
Strepsodus sulcidens (*Atthey*).
Cœlacanthus elegans *Newb.*
Ctenodus.

A similar list of fish remains from this locality, said to be from the roof shale of the Jewel, has previously been published by Dr. Traquair.* It is stated by Hugh Miller † that he was shown by Mr. Cadell the casts of some remarkable reptilian footprints in the roof of one of the coal seams in the old Smeaton Colliery, but the horizon of this seam is not known.

It is difficult to understand the physical disposition of the Smeaton Coals in relation to the measures above them. In the old mining plans a level course in the Beefie Seam proceeds in a direction slightly west of north, though the overlying beds in the South Esk, hardly a quarter of a mile farther west, are striking nearly east and west.

The Old Smeaton workings are bounded on the south-east side by a large fault, passing, in the Jewel seam, about 500 yds. north of Cowdenfoot. This dislocation is generally supposed to have a large downthrow to the east, perhaps as much as 500 ft., and it seems probable that it is a continuation of part of the Sheriffhall fault. The beds on the south-east side have been explored by various bores, and include a series of coals which are supposed to belong to the Cowpits series.

Farther south near Cowdenfoot these beds are probably traversed by two faults, each with a downthrow to the north. The more southerly one runs east and west a little south of Cowden Cleugh and has for many years been regarded as the prolongation of the Sheriffhall fault, but recent borings near the head of the Cleugh show that its throw there is not large. The other dislocation, to the north, is inferred from the details of a bore put down 300 yds. north-east of Cowdenfoot and from the outcrops at the western end of the Cleugh. From the boring information it would appear that the top of the Roslin Sandstone series is not likely to outcrop west of a certain line, between which and the beds at the western end of the Cleugh there is not sufficient room for the whole succession of the Roslin Sandstone. It is therefore supposed that a fault passes between the bore and the Cleugh. Certain boring operations lately carried on by Mr. R. T. Moore, who has kindly communicated the details, have proved that the ground a little north-east of Langside Head is considerably troubled, and perhaps the supposed fault near Cowdenfoot may continue through the troubled area, though it cannot have a large throw in that locality.

A marine calcareous horizon, often two or three feet thick, which crosses the North Esk about a quarter of a mile above the junction of the North and South Esk, and the South Esk about 230 yds. above the same point, is taken as the top of the Lower Coal Measures. Some of the calcareous seams and lenticles in this horizon are slightly carbonaceous, while others are composed of

* *Op. cit.*, p. 697.

† "The Testimony of the Rocks," 1887 ed., pp. 72–73, and "Edinburgh and its Neighbourhood," 1870, p. 80.

compact grey or buff limestone and show "cone-in-cone" structure. The following fossils, determined by Dr. Lee, have been found in this zone:—

Spirifer sp. indet.
Chonetes sp. indet.
„ aff laguessiana *de Kon.*
Productus longispinus *J. Sow.*
Pleuronautilus costatus *Hind.*
Orthoceras sp. indet.

It may be mentioned that very near the above marine horizon Mr. Tait has also collected the following fish remains, which have been named by Dr. Traquair:—

Pleuroplax attheyi (*Barkas*).
Elonichthys aitkeni *Traq.*
Acanthodes sp.

The above fishes are of estuarine types and must have been obtained from a position slightly different from that of the marine fossils.

In reference to the marine fossils Dr. Lee has supplied the following note:—

"The specimen referred to *Productus longispinus* J. Sow. seems to differ in no way, so far as its external characters are concerned, from the common Carboniferous Limestone form. This observation, however, is quite in accordance with what has been observed in regions where marine conditions prevailed during Upper Carboniferous times, as for instance in Russia. The typical specimens of *Productus longispinus* found in the Middle and Upper Carboniferous beds of that country show that the species is to be considered as a persistent one, hence its presence here in an unmodified form.

Pleuronautilus costatus Hind is represented by a large, but imperfect, specimen. The specific characters are, however, so clearly exhibited that the fossil can safely be referred to this species, which was founded by Dr. Wheelton Hind on specimens obtained in the North Staffordshire Coal-field, below the Gin-Mine Coal." *

This marine horizon at Dalkeith may possibly be in the same position as that found near the top of the Lower Coal Measures of Fife.† The general aspect of the strata changes below this zone, for they bear a great resemblance to the productive measures below. First we find a coal from 8 to 13 in. thick, with a grey fireclay seat, and about 36 ft. farther down there is another seam from 11 to 15 in. thick.

A grey clay on the east side of the South Esk, a few feet below the probable position of the lower of these two coals, contains *Leaia* or *Estheria* and remains of the following plants determined by Dr. Kidston:—

Eremopteris artemisæfolia (*Sternb.*).
Sphenopteris obtusiloba *Brongt.*
Neuropteris gigantea *Sternb.*
Carpolithus perpusillus *Lesqx.*
Samaropsis sp.

* "On the Palæontology of the Marine Bands in the Coal Measures," *Quart. Jour. Geol. Soc.*, 1905, vol. lxi. p. 540.

† "The Geology of Central and Western Fife and Kinross," *Mem. Geol. Sur.*, p. 147. See also Mr. James W. Kirkby, "On the Occurrence of Marine Fossils in the Coal Measures of Fife," *Quart. Jour. Geol. Soc.*, 1888, vol. xliv. p. 747.

All these plants are said to be common to the Lower and Middle Coal Measures, and they are found again in clay shales, which must be on a much lower horizon, just above the level of the Esk on the west side about 300 yds. south-west of Smeaton Bridge. The full list of organic remains which have been collected from the latter locality is given below:—

Eremopteris artemisæfolia (*Sternb.*).
Sphenopteris obtusiloba *Brongt.*
Neuropteris acuminata (*Schoth.*).
„ gigantea *Sternb.*
„ heterophylla *Brongt.*
Calamites.
Sigillaria.
Leaia leidyi (*Lea*).

A little above the clay shale just referred to comes a sandstone, 2 ft. thick, in which Mr. Tait observed, in a space 12 ft. long, no less than nine or ten erect *Calamites*, most of them about half an inch broad and a foot or more in length. It may reasonably be inferred that the process of sedimentation was very gentle and at the same time rapid, so as to permit of these plants being entombed in an erect position.

About 50 yds. below the junction of the North and South Esk and in stratigraphical position perhaps about 170 ft. below the marine limestone with *Spirifer*, we find a thin carbonaceous limestone, about a foot thick, underlaid by a fireclay and a flaggy yellow sandstone which is probably more than 60 ft. thick. Near the base of this sandstone a bore has been put down to a depth of 205 ft. without reaching any coal, so that the distance between the *Spirifer* limestone and the Splint Coal (of Craighall) is probably not less than 440 ft. in this locality. C. T. C., E. M. A.

COAL-FIELD SOUTH OF THE SHERIFFHALL FAULT.

The Glenesk, Polton and Whitehill pits, active in 1903, are all shallow and working in beds which are nearly flat or lying at gentle angles and but little disturbed by faults. The centre of the basin in the Whitehill Colliery lies about 630 yds. slightly south of east of the winding shaft, and the Splint Coal in this locality is at a depth of 417 ft. beneath the surface. In Polton Colliery the centre is about 666 yds. slightly south of west of the winding shaft.

The following tables give in an abbreviated form the sections of the shafts at Whitehill and Polton Collieries:—

Section at Whitehill Colliery, Rosewell.

	Ft.	In.
Strata, chiefly sandstone	47	8
Crow Coal	4	2
Strata	10	4
Coal	1	1
Strata	17	5
Coal	1	6
Strata including two thin Coals	46	10
Great Seam Coal	6	2
Fireclay and blaes, etc.	6	0

	Ft.	In.
Sandstone, "Rough Coal Post"	34	1
Soft white blaes	1	6
ROUGH COAL	3	6
Fireclay and blaes	3	6
Sandstone	11	10
SPLINT COAL	2	0
Strata	23	10
PARROT ROUGH COAL	3	9
Strata	12	9
JEWEL COAL	2	6

Section in Polton Colliery, Bonnyrigg.

	Ft.	In.
Soft sandstone	27	11
Blaes	0	9
Soft sandstone	25	6
Blaes and bands	7	5
Brown sandstone	27	1
Alternating strata	27	11
Coarse white sandstone	54	4
COAL	1	0
Fireclay	2	6
Coarse white sandstone	13	7
COAL and blaes (GREAT SEAM)	7	1
COAL (GREAT SEAM)	2	10
Blaes (GREAT SEAM)	1	0
COAL (GREAT SEAM)	2	0
White sandstone	26	2
ROUGH COAL	3	0
Strata	12	11
SPLINT COAL	3	2
Strata	15	8
PARROT ROUGH COAL	3	3
Blaes	4	3
JEWEL COAL	2	10
Fireclay	2	0
Hard rock*	11	6
Blaes	0	6
Hard rock	5	6

In the Whitehill Colliery a "blind" pit was sunk to a depth of 74 ft. below the Jewel Seam in search of the Jenny Meggat Coal, reputed to have been formerly worked and found of good quality. No workable coal was found, but it is clear, from the natural section in one of the little streams which runs into the North Esk from the south-east side near Roslin Castle, that a coal, 18 in. thick, of good quality, occurs at a greater depth—perhaps between 100 and 125 ft.—below the Jewel Seam. It there rests on a few feet of shaly fireclay overlying a thick coarse sandstone—the top bed of the Roslin Sandstone series—and probably corresponds to the lower of the two Melville Coals, which is said to have been formerly worked near Elginhaugh.

The section between the Jewel and the lower coal just mentioned comprises in its lower part a considerable proportion of fireclay and shaly clay often with ironstone nodules. In the upper part, just below the seat of the Jewel Coal, a massive coarse sandstone appears which has a considerable resemblance to the top bed of the Roslin Sandstone series. In places it is 40 ft. thick and seems persistent

* Probably sandstone.

on the west side of the basin, being seen at the Broomieknowe railway cutting, near Elginhaugh, and close to Roslin Castle. It lies under the Broomieknowe railway bridge and is also quarried on the south side of the line near this bridge, so that it may be conveniently called the Broomieknowe Sandstone.

The beds a little above the Roslin Sandstone are exposed in the southern bank of the Esk in the large bend south of Roslin Castle. No coal is seen resting on the sandstone in this locality, but it is possible that a seam may occur there hidden under the talus below a steep slope of clay shale, in which Mr. Tait found, at a height of about 20 ft. above the line taken as the top of the Roslin Sandstone series (Millstone Grit), a band containing a few specimens of *Edmondia*.

Several thin coals generally occur a little beneath the Broomieknowe Sandstone. The lowest of these—perhaps on the average about 30 ft. below the sandstone—is underlain by an impure black-band ironstone from 2 to 5 in. thick, in which the ironstone portions appear in small irregular lumps and streaks, giving the rock a brecciated aspect.

Several of the beds—including the Splint Coal, the rough portions of the Parrot Rough, the Jewel Coal and one of the thin coals under the latter—which are exposed in the Broomieknowe cutting, have been found by Mr. James Bennie and Dr. R. Kidston to contain spores of Lycopods.*

The Jewel Coal has not been found in good condition in the collieries on the Rosebery Estate, west of the main Whitehill workings, and it seems entirely absent in many places. As the Jewel and the Parrot Rough often occur within 4 or 5 ft. of each other it is usually unsuitable to work both seams; the former is generally mined on account of its superior quality.

In the Whitehill shaft section the Rough Coal is separated from the "Rough Coal post" by 18 in. of blaes, but in the Polton shaft section and in exposures near Elginhaugh and Newbattle Abbey the two are in direct contact.

Near Elginhaugh, the lower portion of the Coal Measures is laid bare. The section displays the Jewel Coal, the Parrot Rough, Splint and Rough Seams and a higher coal which is separated from the Rough Seam by about 30 ft. of massive yellow sandstone—no doubt "the Rough Coal post"—and some fireclay. Of the highest coal only 15 in. is visible, but it seems probable that it corresponds to the Great Seam of Whitehill, as at Polton Colliery this seam is much mixed with shale and too poor in quality to be worked, and in two bore holes near Glenesk it is represented by a thin coal only from 1 to 4 in. thick.

The Jewel Coal is not now exposed in the North Esk, but its position is known, and it is seen at the entrance of an old day-level, a short distance south of the river, where it is about 33 in. thick and lies a little above a massive, rather coarse sandstone—the Broomieknowe Sandstone.

The Parrot Rough Coal at Elginhaugh is about 4 ft. thick, and in the middle includes a 7-in. seam of parrot shale which

* "On the Occurrence of Spores in the Carboniferous Formation of Scotland," *Proc. Roy. Phys. Soc. Edin.*, vol. ix. p. 82.

is very persistent in the southern part of the basin, being seen at Newbattle Abbey and Broomieknowe, as well as in the Polton and Whitehill Collieries. This shale was formerly used as an oil producer and was sent to the Edinburgh gas works; it is still used in the Rosewell gas works.

In the shale a little above the Parrot Rough seam we often find, as already stated, a band of ironstone nodules containing remains of *Carbonicola robusta*. At Elginhaugh these fossils occur about 15 in. above the coal and are associated with *Spirorbis*. At Broomieknowe they lie between 25 and 30 in. above the coal.

The best section near Newbattle Abbey is in the little stream that joins the South Esk from the east side, close to the Abbey. Here the Rough Coal is to be found immediately under a thick, yellow, massive sandstone—the Rough Coal post. The Splint Seam is not visible, but its position may be represented by a gap in the section, below which comes the Parrot Rough, without any indications of *Carbonicola* above it, but with a parrot shale, about 6 in. thick, at the base. The Jewel Coal of the Whitehill and Polton Collieries is not exposed in this locality, and it is doubtful whether it exists. The Rough Coal and perhaps the underlying seams have evidently been wrought in old times near the surface on the east side of the Esk near the Abbey. It appears that the monks of the Abbey mined for coal in the early years of the thirteenth century,* and it is highly probable that they first turned their attention to the nearest seams exposed at the surface.

In the little burn on the east side of the road, about 370 yds. S.S.E. of Newbattle Bridge, a coal, at least 2 ft. thick, crops out, and, from its character, was identified as the Splint Coal of Polton Colliery, by Mr. Stirling, the former manager of this colliery. In a Report by D. Landale,† made in 1857, it is stated that the Eldin Rough and Splint Seams have been worked in the Bryant's day-level (300 yds. south of the road-bridge over the South Esk, near Newbattle Parish Church) and have also been found at the crop near Craig's Paper Mill (now pulled down) close to the Lothian Bridge (railway bridge over the South Esk).

On the east side of the South Esk, about 160 yds. S.S.W of the Abbey, a coal, at least 3 ft. thick, rests on 21 in. of fireclay which overlies the yellow sandstone already spoken of as the Rough Coal post. This coal is in all probability the Great Seam of Whitehill.

In Aitkendean, near Carrington, several coals, and old abandoned day-levels and shallow pits are to be seen. One of the seams resembles the Rough Coal in quality, and like it is directly overlain by a thick massive sandstone, rather coarse and either red or yellow in colour. It is split up by partings, the section being somewhat as follows:—

	Ft.	In.
Coal	1	3
Clay	0	2
Coal	1	6
Fireclay and sandstone with rootlets	2	0
Coal	0	8

* See p. 231.

† This information has been kindly communicated by Mr. J. Gemmell, C.E.

Two other lower coals are also seen a little farther down the dean, and the bottom one is at least 30 in. thick.

The Rough Coal is said to be only 9 in. thick at the old Eldin Dean pits, about 670 yds. east of Broomieknowe Station. It is not visible in the Broomieknowe cutting, though the strata near its stratigraphical position are well exposed.

The Crow Coal near the top of the Whitehill shaft section is, as its name implies, of poor quality, and has not been worked in the present pit. A coal, supposed to be the equivalent of this seam, was, however, formerly worked at Barleydean.

At Eskbank, the Dalkeith Under and Upper Coals lie above the horizon of the Great Seam. Both were formerly worked near the outcrops, and the Under Seam was lately mined in the Glenesk Colliery. From the journal of the bore, put down 50 yds. north of the upcast shaft of the colliery, the following shortened section has been constructed:—

Section in Bore near Glenesk Colliery.

	Ft.	In.
Strata	1	0
Coal with partings. Probably the Cowpits Little Splint	3	4
Strata	6	8
Coal and blaes	2	4
Strata	14	8
Dalkeith Upper Coal (waste)	5	10
Strata	18	7
Brown sandstone	36	9
Strata	19	4
Dalkeith Under Coal	2	8
Strata	12	7
Coal and parting	1	7
Faky fireclay	1	9
Sandstone	40	8
Strata	86	5
Coal	0	1
Sandstone	26	3
Strata	12	7
Rough Coal with parting	2	10

From the foregoing section it is apparent that the Dalkeith Under Coal is nearly 182 ft. above the Rough, while at Whitehill the distance between the latter seam and the Crow Coal is about 125 ft. In the section in the Polton shaft, which is half-way between Glenesk and Whitehill, the Dalkeith Under Seam is not represented, though the thickness of strata above the Rough is 227 ft.

The one-inch coal in the Glenesk Bore section perhaps represents the Great Seam, and the thick sandstone beneath it the Rough Coal post.

In a Report made by D. Landale, in 1857, it is stated that the crops of the Upper Dalkeith Coals have been worked at the Newbattle Kirkyard. A seam which may correspond to one of the Dalkeith Coals is visible in a little burn north of Woodburn House, where it has the following composition:—

	Ft.	In.
Coal	0	6
Fireclay	1	6
Coal	0	3
Fireclay	1	0
Coal	1	6

This seam is perhaps the one exposed at the east side of the South Esk, 100 yds. slightly north of west of Woodburn. A little above the latter seam we find thin alternations of red and purple shales, flaggy sandstones, and several lenticular seams of compact pale brown limestone, about 8 in. thick. A similar limestone, associated with red and lilac clay shales, is also seen in the North Esk about 300 yds. above Lugton Bridge. These beds resemble some of the unproductive measures (Middle Coal Measures?) in Dalkeith Park, but they are probably much lower in the sequence, and underlie the Craighall Measures, including the Jewel, the Beefie and the Splint Coals.

The coarse red, yellow and purple sandstone, exposed in Dalhousie Burn below Cockpen Church, is known to be about 160 ft. above the Splint Coal at a locality 267 yds. north-east of the Church, and must therefore be at least 100 ft. above the position of the Great Seam. It extends northwards to a little distance below Newbattle Bridge, and is probably separated by a fault, with a considerable downthrow to the south from two exposures of a coal seam—probably the Rough—which occur on the west side of the South Esk about a third of a mile below the bridge. One of these shows 25 in. of coal overlying fireclay and immediately underlying a soft yellow sandstone. On the south side of the exposures, the beds below the coal rise up to the south and extend along the river near to the coarse sandstone referred to, so that it seems probable that somewhere in this locality strata considerably above the Great Seam must be faulted down against beds below the Rough Coal.

The geological structure of the ground in the South Esk, for a third of a mile upwards from the foot of Dalhousie Burn, is obscure. The exposures of the coarse sandstone of the latter stream do not extend up the Esk, but end suddenly at the side of a drift-covered space which may be the site of a pre-glacial valley. Its margin can be traced a short distance up Dalhousie Burn, and at its western edge we find in one place many fragments of thin flaggy sandstone which appear to be nearly *in sitû*. If such be the case, they must be separated from the coarse sandstone on their west side by a fault running in a N.N.E. direction.

The coarse sandstone in the South Esk at the foot of the little stream about a third of a mile above Newbattle Railway Bridge is considered to be part of the Roslin Sandstone series (Millstone Grit). In the space between this exposure and the somewhat similar sandstone at the foot of Dalhousie Burn, which, as already stated, must be considerably above the position of the Great Seam, the horizons of the lower seams of the Coal Measures should come to the surface if not thrown out by faults. There is no evidence at present of the occurrence of any coals in the space mentioned, nor of any steep dip which might cause these seams and the associated strata to outcrop in rapid succession in the obscure part of the river which extends upwards from the foot of Dalhousie Burn for about 180 yds. According to D. Landale's Report, just referred to, the crops of the Rough and the Splint Coals have been found in this locality, but it still seems probable that at all events some of the seams which should normally occur here have been cut out by one or more faults with a downthrow to the north-west. In the Newbattle incline of

the Lady Victoria Colliery, a dislocation with a downthrow to the north-west of 240 ft. has been proved in the Edge Coal group, which probably continues in a south-west direction and crosses the Esk in some part of the space referred to, but the exact position cannot be ascertained. It has still to be proved to what extent the Coal Measures are affected by this dislocation and by another sub-parallel fault on its south-east side with a similar downthrow, which has also been proved in the Edge Coal group.

The Vogrie fault probably traverses the Mid-Lothian Basin not far south from the southern margin of the Coal Measures except at one locality, and a branch of this dislocation perhaps forms the southern limit of the Coal Measures for some distance west of the road between Carrington and Temple. In a wooded valley between these villages a coal, formerly wrought with a southerly dip, lies under a soft coarse sandstone and over a massive sandstone which has been quarried. It may be the Rough Coal or some lower seam, but even if this supposition be correct, its occurrence there implies the existence of a fault. For, about a third of a mile to the south near Redside, a coarse red and white sandstone with a W.S.W. dip at 30° is exposed, which has been mapped as part of the Millstone Grit. In this interval there is not sufficient room for the uprise of the coal to the south with a normal outcrop above the Roslin Sandstone.

The south-western margin of the coal basin between Roslin Castle and Newbigging farm is probably formed by a fault striking slightly west of north and with a considerable downthrow to the east, which has already been referred to in describing the Roslin Sandstone series (see p. 248). A bore put down by the roadside about a quarter of a mile E.N.E. of Kirkettle farm pierced 276 ft. of strata before reaching the Castlecary or No. 6 Limestone, and calculating from the dip of the strata in the neighbourhood and from information regarding the adjoining workings of Whitehill Colliery, it seems probable that the fault passes between the bore and the workings. C. T. C.

PENICUIK AND AUCHENCORTH OUTLIERS.

The existence of a small outlier of the Lower Coal Measures, situated nearly in the centre of the Roslin Sandstone area of Auchencorth, is proved by a bore on the Hare Burn, rather less than half a mile above Hare Burn Bridge. The journal of this bore shows two coal seams, 2 ft. 9 in. and 2 ft. 3 in. in thickness, at depths respectively of 15 and 19 fms. from surface. Ten fathoms of this depth is drift, the bore having been put down in a pre-glacial channel of the stream, now filled with sand and gravel.

These coals have been identified with the two lowest seams of the Coal Measures. A lower seam of parrot coal, only 3 in. in thickness, may be included in the Roslin Sandstone, which has been proved to a farther depth of $7\frac{1}{2}$ fms.

Another small patch of Coal Measures occupies the centre of the minor basin, already referred to, immediately to the south of Penicuik. The two lowest coals, the Little Splint and the Jewel, crop out in the river Esk a short distance below the cauld, and are associated with dark shales from which Upper Carboniferous

plants have been obtained. The lowest seam, which at the outcrop is 2 ft. thick, has been recently worked to some extent, but the workings were flooded by the river, and have for the present been discontinued. L. W. H.

II. Middle Coal Measures (?).

Though the members of this group have a great resemblance to the Upper Barren Measures of Fife which are classed with the Middle Coal Measures of England,* yet it must be remembered that no sufficient palæontological evidence has yet been obtained in Mid-Lothian to determine their age.†

The beds provisionally classed with the Middle Coal Measures only occur, as already stated, on the north side of the Sheriffhall fault. They are well seen in Dalkeith Park (in both the North and the South Esk) and also in the North Esk for a little distance above the Park. They have been penetrated by bores in Dalkeith, both near Lugton Bridge and at the brewery belonging to Messrs. M'Lennan and Urquhart. In the river sections the general dip is nearly south, often at angles between 9° and 16°, and in a comparatively undisturbed area, extending from a little north of Montagu Bridge—the private bridge over the North Esk—to the marine calcareous horizon, which is taken as the top of the Lower Coal Measures, there is evidence of the occurrence of nearly 400 ft. of strata, consisting chiefly of rather coarse-grained, occasionally pebbly sandstones of a reddish or brown colour, mixed with red, lilac, grey and mottled clays. A thin calcareous zone, about 230 ft. above the marine limestone just referred to, is also seen in both the North and South Esk, and is mainly represented by a dark grey bed, from 4 to 6 in. thick, which is mixed with some carbonaceous material, and contains many little veins filled with calcite crystals arranged with their long axes nearly at right angles to the sides of the veins. The clay above this bed is also crossed by many thin veins of a similar kind.

From the clay shale close to the carbonaceous limestone, Mr. Tait has collected various organic remains; including Upper Carboniferous fishes, a bifurcating stem and *Lepidostrobus*, but these might be referred either to the Lower or Middle Coal Measures. The fish remains have been named by Dr. Traquair as follows:—

Cœlacanthus elegans *Newb.*
Helodus simplex *Ag.*
Megalichthys sp.
Sphenacanthus, shagreen of.
Palæoniscid scales (indeterminable).
Selachian teeth.

About 100 yds. north of the Montagu Bridge a fault running nearly east and west crosses the river, on the south side of which a bed of carbonaceous limestone and mottled clays again occur.

* "The Geology of Central and Western Fife and Kinross," *Mem. Geol. Sur.*, p. 146. "On the Various Divisions of British Carboniferous Rocks as determined by their Fossil Flora," R. Kidston, *Proc. Roy. Phys. Soc. Edin.*, 1893, vol. xii. p. 203.

† The lowest of the Fifeshire beds, from which Mr. Kirkby collected the fossils which indicated to Mr. Kidston the palæontological horizon, lies more than 500 ft. above the base of the Upper Barren Measures.

These closely resemble the strata just referred to, except for the occurrence among them of a red sandy shale, exposed about 50 yds. north of Montagu Bridge, where it yields marine fossils first detected by Mr. H. B. Maufe. The forms obtained by him and subsequently by Mr. Tait were determined by Dr. Lee and are given in the subjoined list:—

Lingula mytiloides *J. Sow.*
Productus sp. (*a*) (of the group of *Pr. scabriculus*).
„ „ (*b*) (affinities doubtful, but not the same as preceding).
Lamellibranch (?) indet sp. (*a*).
„ (?) „ sp. (*b*).
Pectiniform lamellibranch.
Nautiloid indet.

If the fault just referred to has no appreciable throw, the stratigraphical position of this fossiliferous zone is probably about 380 ft. above that of the marine band which has been taken as the top bed of the Lower Coal Measures, as already described.

In the North Esk, on the south side of Dalkeith Park, there is a development of soft, red, purple, and white sandstones alternating repeatedly with mottled red, buff, and white marls or clays, about 80 ft. thick. The sequence is not quite like any seen within the Park, and it is probable that the component beds are higher in the series than any of the other red measures exposed. It is doubtful whether they directly overlie the strata on the north side of Montagu Bridge. A little below Lugton Bridge these alternating beds dip north-west about 25°, and by the old toll-house on the south side of the bridge they have been penetrated in three bores, made to provide a water supply for the town of Dalkeith. No coal is recorded in any of these bores. The central bore is 337 ft., and the western 241 ft. in depth. The boring contractor stated that the strata pierced in the latter are much confused and often almost vertical, thus indicating marks of disturbance of the strata. It seems probable that the site is not far from a branch of the Sheriffhall fault.

A diamond boring has recently been made from the bottom of an old well in the yard of Messrs. M'Lennan and Urquhart's Brewery—about 300 yds. E.N.E. of the Dalkeith Station. The site lies to the south of the position previously assigned to the Sheriffhall fault, but the close resemblance of the strata in the bore to the supposed Middle Coal Measures of Dalkeith Park leaves little room for doubt that they belong to the same series. It is to be noted, however, that the details of the sections in the Park and in the bore differ considerably. While in the former area only one calcareous horizon is known, in the bore three are represented, each by more than one thin bed of limestone. Several of these calcareous bands have a brecciaform appearance, being composed of small irregular lumps of buff limestone embedded in clay shale; certain laminæ in them are nearly black, apparently from a slight admixture of carbonaceous material, but no proper coal appears to have been met with. The total depth of rock pierced in the well and in the bore is rather more than 350 ft. The cores showed that the strata are nearly flat, though it is probable they are only a short distance north of the main branch of the Sheriffhall fault.

At Olive Bank, Musselburgh, the total thickness of Carboniferous rocks above the Splint Seam of Craighall is about 529 ft. while near Dalkeith the marine limestone taken as the top of the Lower Coal Measures is perhaps about 440 ft. above the same horizon. It thus seems likely that some of the supposed Middle Coal Measures may occur at Musselburgh also, though none are exposed. Below the raised beach and drift deposits and above two thin beds of kingle, the Journal of No. 1 Bore there records rather more than 130 ft. of strata, chiefly consisting of alternations of red sandstone and red blaes and barren of coal, which may possibly belong to the group under description. A conjectural boundary line has been drawn upon the map in accordance with the scanty evidence, the area enclosed being about a quarter of a square mile. C. T. C.

CHAPTER XIV.

IGNEOUS ROCKS INTRUSIVE IN CARBONIFEROUS STRATA.

Reference has already been made to the important series of igneous rocks that have invaded the Carboniferous strata in the region under description and appear in the field as intrusive sheets or dykes. They may be arranged in two groups which differ in petrographical characters and in age. Within the area there is evidence to prove that some of the sills are more or less persistent on certain horizons and have been folded and faulted with the Carboniferous sediments among which they lie.

The earlier intrusions have characters linking them to the Lower Carboniferous lavas. They often carry olivine and show indications of a considerable quantity of alkali in their composition, such as the frequent presence of analcime. They have been intruded contemporaneously with the surface outpourings and can be regarded as the underground expression of this volcanic episode—a conclusion supported by their absence above the Index Limestone in this district. The picrites belong to this earlier group.

The later set including the east and west dykes, in addition to several great sheets, resembles the Whin Sill, both in age and composition.* The exact age of this group, including all the quartz dolerites, is not well defined within the margins of the region at present under description. In the Mid-Lothian basin, however, east and west dykes intersect the Coal Measures, and to the west of Linlithgowshire the sheets are abundant in the Coal Measures and have been faulted with them.†

In the Bathgate Hills, Mr. Clough observed that a quartz dolerite sheet, which appears to be continuous with an east and west dyke, cuts another of these dykes.‡ This sill has been faulted with the Carboniferous beds in which it lies, as will be seen from the detailed description in a subsequent page. These facts appear to limit the date of the quartz dolerites, both sills and dykes, to a very late part of the Carboniferous period ; a conclusion in accord with Mr. Clough's observations in Cowal, where he found north-west dykes of Tertiary age repeatedly cutting east and west dykes.§ It is interesting also to note that the Hett dyke, associated with the Whin Sill and of similar composition, traverses the Coal Measures, but on reaching the escarpment of the Magnesian Limestone does not penetrate it.‖ In the few cases where the relations between the two groups are seen, the quartz dolerites cut the teschenite intrusions. This point has been established south of Wester Ochiltree by the Geological

* The Petrography of these two groups is dealt with fully in Chapter XV.
† Explanation of Sheet 31 (1879), p. 45.
‡ "Summary of Progress," *Mem. Geol. Sur.* for 1904, p. 118.
§ "Geology of Cowal," pp. 139, 147. Sir A. Geikie, "Ancient Volcanoes," vol. ii. p. 172.
‖ A. Sedgwick, *Trans. Camb. Phil.*, 1827, vol. ii. p. 42.

Survey,* and by Mr. Campbell and Mr. Stenhouse, in Inchcolm, where sills of the earlier group are traversed by east and west dykes (see Plate V.).

Before entering into details regarding some of the more important and interesting members of these groups, one or two facts relative to their general disposition deserve attention. At a first glance it is evident that these rocks are not equally distributed over the district now under description, and on examination it will be found that, with the exception of a few east and west dykes, none occur east of the Pentland fault; while to the west of that line of displacement they are profusely abundant, particularly in the oil-shale field. Here the oil-shales seem to have afforded easy paths, enabling the igneous rock to replace the volatile constituents driven out before it.

G. W. G.

EARLIER GROUP OF INTRUSIVE ROCKS.

OLIVINE DOLERITE, TESCHENITE, PICRITE.

These are found in sheets occasionally associated with the lavas, but more often occurring in the sediments below them. Perhaps the most remarkable example is Salisbury Craigs, a semicircular mural escarpment due to the outcrop of an intrusive sheet of teschenite (Plate III.). Occurring close to the Scottish metropolis it is natural that such a prominent feature should have attracted attention from the earliest days of geology. The followers of Hutton and Werner pointed to this intrusion as furnishing evidence in favour of their rival theories regarding the origin of trap-rocks.

It has been injected nearly along the line of junction of the Upper Old Red Sandstone and Carboniferous strata. Evidence of intrusion is best seen towards its northern end where it pierces the red sandstones beneath and the cementstones above. At the south end it interdigitates with beds containing *Holoptychius* and dies out before reaching the agglomerate within the neck. The sill dips inward toward the neck which probably already existed at the time of its intrusion. Samson's Ribs is not, as formerly believed, in continuity with Salisbury Craigs, but is a separate intrusion of different petrographical type, within the neck (see p. 67).

The rock of Salisbury Craigs varies considerably in texture in the field. From the margins inwards towards the centre it is arranged in corresponding parallel zones due to cooling. The margin is fine-grained, with a thin film of tachylite, often reddened and decomposed at its outer border. A line of small round vesicles separates this marginal band from an inner coarse-grained and columnar rock, which forms the greater part of the intrusive sheet and merges into a still coarser central zone with large vesicles. This central band, from 6 to 8 ft. thick, separates into irregular, rounded masses, in marked contrast with the columnar structure above and below. The central portion is more acid in composition than the columnar zones, which is probably due to differentiation of the magma after intrusion. Notwithstanding this feature, both rocks are analcite olivine dolerites or teschenites (see p. 296).

* "Summary of Progress," *Mem. Geol. Sur.* for 1904, p. 118.

The alteration produced by the dolerite is best seen at both ends of the sill. At the north end it is not visible at the bottom of the intrusive sheet, but at the south end, where it interdigitates with the red sandstones, contact metamorphism is displayed both above and below the branches into which it has split. This alteration is particularly well exposed at the quarries, at the Hawse, and along the Radical Road where the inclusion occurs that was figured by Sir A. Geikie * in the previous edition of this memoir and so carefully studied by Dr. Stecher.† At the junction, the sandstones are converted into a kind of quartzite and the shales become jaspery. Tachylyte borders occur round the inclusions as well as at the margins of the mass, and in these places little dykes of dark porphyritic rock are found (Plate XI. Fig. 6).

Near the Cat Nick some dykes that may belong to the later east and west group are seen traversing the sill. Their direction cannot be determined, and they are too decomposed for microscopic determination. B. N. P.

Low down in the Calciferous Sandstone series a sill forms the bold escarpment of the Kaimes and Dalmahoy Hills and occupies a very constant horizon in the Ballagan group, some little distance above the Corston Hill lavas. On the western slope of Dalmahoy Hill there is an excellent section showing that the mass consists of several separate intrusions, the lower portion being columnar. The rock is extensively quarried for road metal. Near the same stratigraphical position the sill at Auchinoon, about a mile to the south of Corston Hill, shows a fine contact junction on the north side of the road, where the intrusive rock has converted some calcareous shales into a calc-silicate hornfels. East of the road another mass occurs, but the ground is so obscured by drift as to render its position uncertain. Farther west, the sill at Camilty Mill on the Linhouse Water also occurs above the Corston Hill lavas, and may be seen in that stream.

The most extensive intrusive sheet in the district is the Broxburn sill, regarding which much information has been obtained in the course of mining operations. At Newfarm, east of Livingston, it does not appear on the surface, and its outline beneath the drift has been laid down from borings. To the north it passes below shales and merges into the mass beneath Houston Wood, where it occupies the position of the Broxburn Shale and overlies the Binny Sandstone. Two diamond bores, which reached the Burdiehouse Limestone, pierced the sill at that locality, the thickness of the igneous rock passed through in the east boring being 230 ft. (see Fig. 7, p. 88). At the surface the dolerite is seen only in the quarries near Craigs, but a large number of bores have proved its position over the rest of the area. Proceeding northwards, we find the extension of the Houston Wood mass on the farther side of the Middleton Hall fault. Here the sheet was evidently intruded into the strata when they were fairly horizontal, and has shared with them in the dynamic movements which folded and faulted the oil-shale measures. The section,

* See Fig. 19, p. 113, "The Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861.

† *Tscherm. Min. Mitth.*, 1888, vol. ix. p. 145, and *Proc. Roy. Soc. Edin.*, 1888, vol. xv. p. 160.

from Dechmont to the River Almond, published in the Memoir on "The Oil-Shales of the Lothians" (Fig. 14, p. 55), shows that the result has been to bring the sill to the surface at five separate localities. On the east side of the basin, south-west of Newliston, the sill, 80 ft. thick, occupies the position of the Broxburn Shales, rendering them useless. It continues on this horizon to a little beyond the East Mains bore-hole where it rises about 50 ft. above the shales and keeps this level till within a short distance from the mouth of the Albyn mine, leaving the shale uninjured. Here it splits into two, the lower portion being in close proximity to the shale, which it has burned for a short distance inwards from the mine mouth. Mr. Cadell * remarks that this part was found to be full of cavities coated with calcite and filled in the heart with mineral wax, yellowish grey when fresh, and brown after exposure to the air. On analysing the hydrocarbon it was found by Mr. Steuart to consist of—

	per cent.
Carbon	84·35
Hydrogen	12·83
Nitrogen	1·68
	98·86

with traces of sulphur in some specimens. On the west side of the Broxburn anticline the sill alters its position and lies between the Fells Shale and the Houston Coal from Niddry Burn to the Middleton Hall fault. It is not seen at the north end of the Fivestanks basin but appears to the south of Newbigging, on the west side of this flexure, occupying the same position as on the eastern edge. Here the sill forms the Newbigging Crags, and at the south end of this escarpment, changes its horizon and occupies the place of the Houston Coal as far as the east and west Curledubs fault. Six hundred yards to the north-east of Fivestanks, boring operations proved it to have rendered the coal "blind" and to have hardened the overlying Houston marls. On the south side of the Curledubs fault it again descends to the Fells Shale position forming the picturesque crags on which Old Uphall is situated, where it probably attains its greatest thickness. As it approaches the Middleton Hall fault it again rises to take the place of the Houston Coal, and near this fracture it plunges down below that horizon. In a boring to the south-west of Houston House this sheet is 62 fms. from the surface, 252 ft. thick, and occupies the position of the Broxburn Shale.

South of West Broadlaw three small areas, either plugs or sills, lying some distance below the Houston Coal may also belong to the Broxburn sill.

Passing now to other sheets on similar horizons to the Broxburn intrusion, and perhaps belonging to it, we find several small sills on the south side of the Winchburgh fault at Winchburgh. Two of these are well exposed at the south end of the canal cutting, where they are separated by a narrow belt of shale. Their position is just above the Fells Shale. The Winchburgh sheet on the north side of the fault is well exposed in several rock knolls on the east side of the station, and in a rock cutting on the mineral railway of

* H. M. Cadell, *Trans. Inst. Min. Engrs.*, 1901, vol. xxii. p. 347.

the Oakbank Co. Its geological position lies between the Burdiehouse Limestone and the Dunnet Shale and below the position of the Broxburn sill. The Carmelhill and Dundas Castle sheet lies in the Binny Sandstone, a position below that of the intrusion south of Winchburgh of which it may be a continuation. West of Kirkliston, four small sills occur, but their position in the sequence is uncertain.

Between Craigbrae and Craigie, numerous bores have been put down with the result that the drift-covered area between these two points is found to be occupied by dolerite, which has been proved along the southern edge to be about 150 ft. above the Dunnet Shale, and probably 450 ft. in thickness. Further investigation alone can show whether these sills at Craigbrae, Dundas Hill and Winchburgh are extensions of the great Broxburn sheet.

The Mons Hill sill occurs on a lower horizon along the southern shore of the Firth of Forth, and is comparable with the Broxburn intrusion in size. At Whitehouse Point it lies 555 ft. below the Burdiehouse Limestone. In addition to a rudely banded structure dipping to the west, it shows a fine contact junction on the shore where the igneous rock passes beneath greenish grey shales and has altered them considerably. Like the Broxburn intrusion, this sill has been folded with the beds among which it lies, so that it appears again farther west along the crest of the anticline that stretches from Lin Mill Burn, at Port Edgar, to the Ochiltree fault. Near the mouth of this burn it is seen rising from beneath the sandstone beds where it has a rude banding dipping to the east and resembles the Mons Hill sheet in character and texture. Inland it reaches the Ochiltree fault and at one point rises above the Burdiehouse Limestone. Westwards it reappears in the centre of the Hopetoun anticline where it is reduced to a thin sill 200 ft. below the Burdiehouse Limestone. Here it is a white or yellowish rock with cavities full of bitumen similar to those of the Broxburn and Binny Craig districts. On the west side of the anticline it appears spherulitic in the hand specimen. J. S. G. W.

The mass of dolerite which forms Corstorphine Hill lies at its southern end on the Craigleith Sandstones, and as it is traced northward it penetrates the overlying Wardie Shales, which are seen in a highly altered condition in a quarry one-third of a mile S.S.W. of Craigcrook Castle.

The greater part of the rock is a dolerite, but, in the section* exposed in the railway cutting west of Davidson's Mains, it is seen to be heterogeneous, containing a mass of deeply weathered picrite, which is separated from the base of the dolerite by a few feet of rock (see Sheet 32). The more basic portion here forms nearly half the thickness of the mass and is affected by a rude banding parallel with the surfaces of the sheet. It is evident that both rocks form one intrusion which has segregated into these different parts with no chilled margin between them. The picrite is traversed by veins of dolerite and felspathic segregations. Below this intrusion a fine section of altered sediments is exposed. G. W. G.

Wherever sections across the strata between the Craigleith

* H. W. Monckton, *Quart. Jour. Geol. Soc.*, 1894, vol. l. p. 39; also Sir A. Geikie, "Ancient Volcanoes of Great Britain," 1897, vol. i. p. 450.

Sandstones and Wardie Shales are laid bare, in the neighbourhood of Edinburgh, sills are found which appear to be continuations of the Corstorphine sheet, as, for example, the intrusions of Bells Mills, on the Water of Leith, which are noted for having furnished Sir James Hall with material for his experiments. Others occur in the suburban railway cutting near Craiglockhart and at Lochend where a sill on this horizon is magnificently exposed in crags and quarries.

Along the shore between the mouth of the Almond and Newhaven, numerous small sills occur sometimes only a few feet in thickness, affording good examples of white trap.

Opposite the mouth of the river Almond, a chain of islands stretches across the Firth, of which Cramond, Inchmickery and Inchcolm are the most conspicuous. These have not been included in the area revised for the publication of the present edition of the map, but from the researches of Mr. Campbell and Mr. Stenhouse it appears that these islands are composed of various analcite olivine dolerites, including as extreme members picrite on one hand and teschenite on the other.*

The most interesting exposure is that of Inchcolm, the structure of which was carefully described by Boué,† who pointed out the anticlinal arrangement of the rocks and the dolerite cropping out towards each side. He observed parts of the mass passing into serpentine by failure of the felspar. The serpentinous rock, he noted, is traversed by strings of chrysotile.

These facts have been confirmed. The island owes its horseshoe form to this anticline whose western limb is cut by a massive east and west dyke, a continuation of that on the shore at Downing Point (Plate V.). Beds beneath the picrite, consisting mainly of a massive sandstone showing curious false-bedding, are exposed along the southern coast. In one or two places where the top of the intrusion is observed, it is overlain by intensely altered shales which pass on the north-west foreshore under a group of lavas and tuffs. Where the junction with the shales is seen at the eastern extremity of the island, the relations are of a complicated nature. At this point the picrite grades upward imperceptibly into the dolerite, at the same time assuming a peculiar banded structure recalling that of the picrites described by Mr. Harker.‡

The island of Carcraig is built up of four superimposed sheets of teschenite. The two lower intrusions are in contact with a series of altered sandstones, shales and a lamellibranch limestone, dipping in an E.N.E. direction. G. W. G.

The Blackburn leckstone, classed by Sir A. Geikie with the lavas, has been examined both in the field and under the microscope, but his interpretation of the relations of the rocks has not been confirmed. The overlying sediments are greatly altered, the ropy surface is paralleled in other intrusions, while the microscope shows that the igneous rock has picked up fragments of the sediments. In the new leckstone quarry, about half a mile south of Blackburn, the upper portion of the rock is teschenite and the lower is a

* *Trans. Edin. Geol. Soc.*, vol. ix. pt. ii. p. 121.
† Ami Boué, "Essai Géologique sur l'Écosse," p. 176.
‡ "The Tertiary Igneous Rocks of Skye," *Mem. Geol. Sur.*, p. 75.

East and West Dyke of Quartz-Dolerite (on right) cutting Sill of Picrite (on left), Inchcolm.

rather hard picrite, as described by Sir Archibald Geikie,* but the divisional line between the two is tolerably distinct, is very sinuous and does not seem to be due to chilling of either rock against the other. South of this quarry, teschenite occurs at the railway viaduct, and in several quarries beyond, where it is worked for road metal. In the railway cutting the outcrop is 150 yds. broad and does not contain any picrite. From this cutting the teschenite has been traced by numerous exposures to Rusha, where the face of the quarry shows about 30 ft. of this material resting on 15 ft. of dark greenish grey picrite. The divisional line is here distinct and nearly horizontal, and there is no chilled margin. The base of the intrusion is not seen, but there can be no great thickness of rock between the bottom of the quarry and the underlying dark sandy shales in the adjoining burn.

A somewhat thinner band, whose margins are composed of teschenite with picrite in the centre, lies to the east of that just described, being separated from it by about 70 ft. of sedimentary strata. J. S. G. W.

From the evidence adduced it is obvious that these picrites are intimately associated with dolerites; the two rocks forming single intrusions. The separation of the ultrabasic portion from the basic material is so sharply defined as to suggest that we see in them examples of Durocher's liquation hypothesis.† According to this the magma has separated on cooling into two immiscible portions, which have become aggregated during the flow of the molten rock.

G. W. G.

The intrusive rock quarried near Bathgate is another example of the earlier intrusions. It is one of quite exceptional type, and even in the field is characterised by lighter and darker portions, the lighter parts abounding in acicular crystals of hornblende. The form of the intrusion is uncertain, but its position seems to be above the Houston Coal and below that of the Hurlet Limestone. E. B. B.

A very fine section is exposed in a quarry at Ochiltree Mill about three miles south-east of Linlithgow where one of the earlier dolerite sills is cut by an east and west dyke. H. B. M.

Mochrie's Crag, 500 yds. south-west of Wester Ochiltree, is formed by a sill below the Houston Coal. The rock has a peculiar appearance, being speckled with light-coloured glancing patches due to analcime. West of Kingscavil, a dolerite appears on the surface, being traceable for about a mile, ending at its southern end against a neck.

G. W. G.

The Burghmuir Bore, No. 1, entered a band of whin at least 24 ft. 11 in. thick, at a depth of 459 ft., and two borings nearly two-thirds of a mile east of this locality pierced "whin fakes" after passing through nearly 40 ft. of drift. It seems probable that these whin fakes represent both the Burghmuir bed and also the sill west of Kingscavil, mentioned above.

C. T. C.

Among the lavas of the Bathgate and Linlithgow Hills there

* *Trans. Roy. Soc. Edin.*, 1879, vol. xxix. p. 506, and "Ancient Volcanoes of Great Britain," vol. i. p. 443.

† J. J. H. Teall, *Quart. Jour. Geol. Soc.*, 1901, vol. lvii. p. lxxix.

are several examples of markedly columnar rock. One instance is beautifully exposed in the quarries at Hillhouse, where it rests on beds above the limestone and transgresses from one horizon to another. About 30 or 40 ft. of rock is visible, being columnar and rarely vesicular in its lower portion, while higher up, the joints become irregular and the rock highly amygdaloidal, which may be indications of the proximity of the upper margin of the sill. A dyke of white trap occupies a fault in the limestone and appears to give off veins from 1 to 3 ft. thick, which become thinner as they are traced away from the dyke and finally die out.* The larger mass may also have been fed by this intrusion.

The other columnar rocks occurring at Hiltly, Kipps Hill, the East and West Kirkton Quarries, may also prove to be intrusive when further evidence is available. G. W. G.

Between Linlithgow and Bo'ness, only one band of rock, a sill or laccolite of olivine dolerite, is known to be of intrusive character. It is exposed close to, and in a little scar 150 yds. E.S.E. of Carriden Church, and was formerly visible on the shore 140 yds. north of the Church, and in another place more than half a mile W.S.W. of the seaward end of Bridgeness Pier. It was originally regarded as a lava-flow, but in the Smithy Coal workings, near the Miller's Pit (620 yds. south of the old Grange House), it suddenly changed its horizon and appeared in the form of a white tongue running along the coal and destroying it.† In a boring 100 yds. west of Carriden Church, the base of the sheet is 27 ft. above the Smithy Coal and its thickness is 76 ft., though, in a new sinking in Carriden Pit, only 400 yds. to the north-west, the thickness is only 4½ ft. and the base is 46 ft. above the coal.

In the new pits, No. 1 and No. 2, Grange and Bridgeness, this sill has recently been pierced. The blocks of it thrown down on the shore bank are all much decomposed and so full of amygdules that the bed would probably have been classed as a lava-flow had no other evidence been available. C. T. C.

LATER GROUP OF INTRUSIVE ROCKS.

QUARTZ DOLERITE SILLS.

The sill at Selms, one mile S.S.E. of Mid-Calder, which, like the Salisbury Craigs intrusion, has been injected nearly along the junction of the Upper Old Red Sandstone and the overlying cementstones, is a strong coarse dolerite, at one time extensively quarried for road metal and paving setts. The sheet that forms a rocky ridge to the south-west of the village of Kirknewton is intruded into sandstones, with cementstones, and lies some little distance above the base of the Cementstone group. Another sheet at Kirknewton Mains occupies a low position in the Calciferous Sandstone series. Near Red Craig, on the Linhouse Water, a very fine contact is seen in the right bank of the stream, where the dolerite indurates and transgresses shales some distance below the Corston Hill lavas.

* "Ancient Volcanoes of Great Britain," vol. i. fig. 165, p. 456.
† H. M. Cadell, *op. cit.* p. 377.

Quartz-Dolerite intrusive in Calciferous Sandstone, Hound Point, North of Dalmeny Park.

The Ratho sill has been delineated from topographical features, and as the ground is thickly covered with drift it is possible that several separate intrusions are included in this area. The large quarries in this mass lie towards its northern end between the canal and the railway, where it occupies a position some distance below the Burdiehouse Limestone. Another prominent intrusion of this type extends from the shore at Snab Point southwards by Cramond to West Craigs, near Corstorphine. In the river Almond it rests on blue shales, with oil-shale bands of uncertain position, and towards the junction the dolerite becomes fine-grained and alters the sediments to some extent. The quartz dolerite of Hound Point, north of Dalmeny Park (Plate VI.),* may be a continuation of the West Craigs mass, thus connecting it with those of Inch Garvie and Inverkeithing, where the rock lies in a syncline dipping from both sides towards the Inner Bay.

Among higher beds of the Calciferous Sandstone series, on the west side of the Broxburn shale field, two intrusions form a ridge stretching from Dechmont village to Dechmont House. The western one is truncated by a large north and south fault with a downthrow to the east. Not far to the N.N.W. another sill forms the ridge between Binny Law and West Bangour, which lies some little distance above the Fells Shale and appears to dip to the north-west, having a bold escarpment along its eastern margin.

The Binny Craig sill lying to the north of the East Binny fault is a peculiar rock, probably a fine quartz dolerite. At Hanging-side it forms the bold escarpment of Binny Craig, and when struck with a hammer the rock there emits a bituminous odour. At this point it lies a little above the Broxburn Shale and has been injected among shales and beds of bituminous blaes, heating them and distilling their hydrocarbons. In 1890 a diamond boring pierced this sill, one mile north of Binny Craig, where it occupies the same stratigraphical position as at the Craig. It was noticed that the basalt core brought from a depth of over 600 ft. was cracked in places, and the fissures were full of a soft yellow substance like vaseline or wax, which melted in the sun and spread in an oily film over the stone. We may well believe that this was due to the distillation by the igneous rock of the hydrocarbons in the shale, and as was to be expected when the seam was tested, it was found to be quite worthless as an oil producer.† This sill appears at the surface, south of Wester Ochiltree, in about the position of the Fells Shale.

Craigton Hill, north-west of Winchburgh, may represent the southern portion of an intrusion in the Binny Sandstone. It is about 100 ft. thick, is truncated at its southern end by the Ochiltree fault and on the west side of the hill shows columnar structure. J. S. G. W.

Along the volcanic ridge of the Linlithgow and Bathgate Hills other masses of quartz dolerite occur. One of these forms Cocklerue,‡ spreading northward towards the Union Canal; another rather

* See "The Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, p. 114, where sketches of this intrusion by Sir A. Geikie are given.

† H. M. Cadell, *loc. cit.*

‡ J. D. Falconer, *Trans. Roy. Soc. Edin.*, vol. xli. p. 366.

smaller one extends eastwards from Easter Carribber. Their intrusive character is placed beyond doubt by the presence of baked sediment adhering to their upper surfaces exposed in some of the deep quarries of the district and elsewhere. The dolerite is fine-grained towards the margin, becoming coarser towards the centre. In these coarser parts the light-coloured micropegmatitic mesostasis becomes unevenly distributed and aggregates into patches varying in extent with the coarseness of the rock, which give some portions a highly characteristic appearance. Occasionally the quartz dolerite is traversed by pink or grey aplitic veins, from $\frac{1}{2}$ in. to 3 in. across.* The Cocklerue mass clearly illustrates some of the characteristic features of these intrusions, for it becomes fine-grained towards the top as if its form had determined the present contour of the country to a considerable extent, while here and there patches of altered sediment are to be found in contact with the rock.

The east and west dyke north of Cocklerue seems to be related in origin to these dolerite sheets. Their composition is practically identical, and the micropegmatite is found aggregated in patches in those places where the dyke is thick, as on the west side of Preston near the larger sheet. It was found impossible to trace the dyke within the sill, and it seems probable that they both form parts of the same intrusion. G. W. G.

South of Cocklerue the intrusion is irregular, appearing sometimes as a dyke and sometimes as a sill running in a general north and south direction along the summit ridge of the hills. A chilled margin transgressing the lavas and ashes and proving the intrusive nature of the dolerite is exposed on the southern shoulder of Cocklerue, and at the northern end of the quarry at Wairdlaw. An interesting section of the base of the sheet on the western face of Cocklerue shows numerous sills of fine-grained dolerite from a few inches to 2 ft. in thickness, separated by bands of fine dolerite breccia. The breccia must have been formed during the period of intrusion, from an early consolidated part of the magma, which was injected by successive intrusions, the edges of which are chilled against the breccia.

As the large east and west dyke, which passes along the southern end of the Torphichen sill, approaches the north and south intrusion, it widens out and passes insensibly into the sill, whilst it is not known to crop out on the east side of the latter. The dolerite of the dyke and that of the sill are indistinguishable both in hand specimens and in microscope slides, and the conclusion seems warranted that the north and south intrusion and the Torphichen dyke are parts of one and the same intrusive mass.

On Cairn-naple Hill the north and south intrusion assumes a dyke-like habit, and runs as a narrow ridge in a southerly direction to the Knock. H. B. M.

The dyke intrusion of the Knock thins rapidly as it approaches an east and west dyke which lies across its path, so that the band passing through the latter is only 3 ft. across and correspondingly fine in texture. To the south of this dyke it makes a short digression to the west and may then be followed by isolated exposures

* H. W. Monckton, *Quart. Jour. Geol. Soc.*, 1895, vol. li. p. 480. See also J. D. Falconer, *Trans. Roy. Soc. Edin.*, vol. xlv. p. 144.

southward to the Ravencraig. Here the intrusion appears as a sheet, similar to its habit at Cocklerue, and is seen at points markedly inclined to the east, contrasting with the westerly dip of the sediments among which it is intruded (Fig. 19).

The base of the sheet at Ravencraig dips to the north-east at an angle of 45° and the ashes on its eastern side also dip to the north-east at about 20°, although the actual junction, where exposed, is vertical. In fact the sheet has brought the beds resting on its dip slope into general parallelism with itself. The intrusion continues to behave in this way along its outcrop farther south through Whitelaw; and nowhere is the contrary dip more clearly seen than in the effects produced by a fault which crosses the hills about midway between that and Ravencraig (Fig. 19). It displaces the outcrops of the bedded rocks and of the sheet in opposite directions in accordance with their contrary dip. South of this fault, for a short space the sheet lies at a lower angle than usual, and a fine-grained offshoot extends from it into a bed of ash, where it behaves as a true sill (Fig. 19). South of Bathgate there is evidence to suggest that the sheet is again displaced to the east by the large fault that terminates the Bathgate Hills. The ground, however, is far too obscure to allow of certainty on this point.

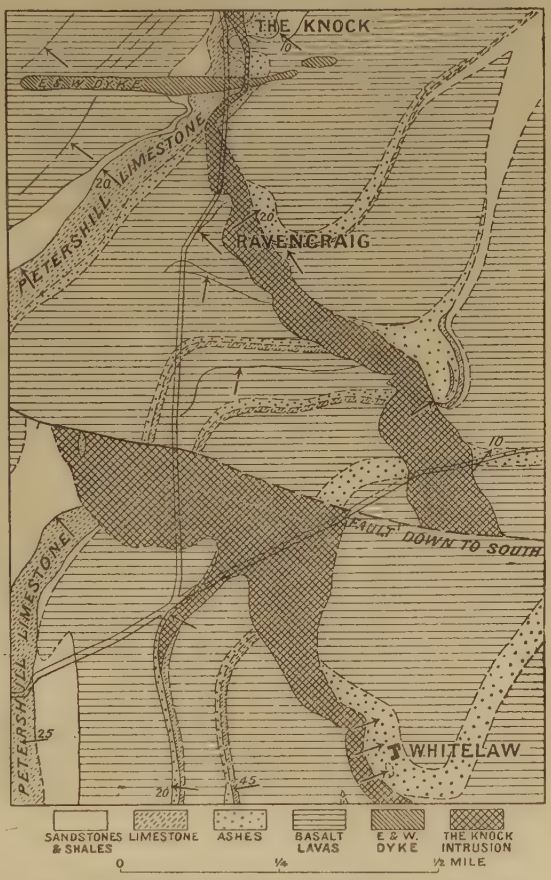

FIG. 19.—Map showing the intrusive sheet of Quartz Dolerite at Ravencraig.

From these facts it is obvious that the sheet is earlier than the east and west fault that traverses it, and it may be asked is it also earlier than the folding? To this question we cannot give a definite reply, but we may notice that the sheet-like habit cannot be entirely due to the folding of a dyke, but is in part clearly original, though perhaps modified by later movements.

E. B. B.

EAST AND WEST DYKES.

Brief allusion may now be made to the east and west dykes of quartz dolerite, some of which have already been referred to. The upper surfaces of these dykes are often irregular, and give rise to discontinuous outcrops. The dyke that runs through Parklycraigs, about half a mile south of Linlithgow Poorhouse, is interrupted in the neck farther east, while south-east of Kingscavil it appears to end in a vertical face as the oil-shale has been wrought across its trend to within a short distance of its outcrop without any trace of it being found.

Exposures of these dykes are sporadically distributed over the sheet. The great dykes that traverse the coal-fields of Lanarkshire and Stirlingshire in the northern part of Sheet 31 (one-inch map) cut across the lavas of the Bathgate Hills and enter Sheet 32. Between Mid-Calder and Clubbiedean Reservoir, and also within the city of Edinburgh and its suburbs, others have been traced for short distances. G. W. G.

In the Mid-Lothian basin a dyke of basalt traversing the Upper Limestone group is exposed in a small wood near the viaduct over Brunstane Burn. Its direction is nearly east and west, but it is not known to extend as far west as the outcrop of the Edge Coals. A second, parallel dyke, about 100 yds. south of the above, has been met with in the Lower Limestone group in the Niddrie Collieries, in a crosscut a little south of Brunstane Burn. Other two, which are nearly in a line with those at Brunstane, are known to cut the strata near Wallyford, on the eastern side of the basin. The more southerly one, about 10 ft. broad, has been pierced at the Wallyford Colliery in the workings of the Five-foot Seam, where it is thin and whitened to the centre. The next occurs only a short distance to the north and had, at the time of the revision, been pierced to the extent of 40 ft. without reaching the other side.

Another dyke, about 100 ft. thick, runs out to sea opposite Prestongrange, where it serves as the foundation of a harbour wall. It has been met almost vertically below its surface outcrop in the workings of the Great and Jewel Seams, though the latter are 120 fms. below sea-level. The most northerly dyke does not appear at the surface in this area, but runs out to sea from Cockenzie Harbour in Sheet 33, where it is about 100 ft. in thickness and unaccompanied by faulting. It is being approached from Prestongrange Colliery. These dykes spoil the coal and are themselves bleached where they come in contact with it. In those cases where they have been pierced, the level of the seams on either side is not altered to any appreciable extent.

W. G., E. M. A.

CHAPTER XV.

THE PETROGRAPHY OF THE CARBONIFEROUS VOLCANIC ROCKS OF THE EDINBURGH AND LINLITHGOW DISTRICTS.

From the days of Hutton the igneous masses around Edinburgh have received a great deal of attention from geologists. The older writers described them under the names of whin, greenstone, trap, amygdaloid, porphyry, basaltic clinkstone and basalt, and in the first years of last century controversy regarding their mode of origin raged between the opposing schools of Wernerians and Huttonians (Neptunists and Plutonists). Jameson and his pupils (following in the footsteps of Werner) adopted a very detailed classification of the rocks, founded on their external characters. The Huttonians were for the most part less skilled in mineralogy than their opponents; but Lord Greenock and Robert Allan have left careful descriptions of the rocks of Edinburgh Castle and Arthur Seat. In his "Essai Géologique sur L'Écosse" Boué has given an account of the superficial characters of the igneous rocks of the Lothians, which is not only in advance of all the work of his predecessors, but was not improved on for many years after the publication of his memoir. Jameson had not published any geognostical description of the rocks around Edinburgh, though he had devoted much attention to them, and Boué, who was a pupil of Jameson, embodies in his work the principal results of his master's investigations, supplemented by the knowledge gained from an acquaintance with the more recent volcanic rocks of Auvergne and the Vivarais. He had also consulted Haüy and Cordier, and hence, as a petrologist, was especially well trained. He divided the rocks into two classes, the "dolerites" and the "basalts," and recognised that they consisted essentially of felspar, augite and iron oxide (often titaniferous), and that many of them contained olivine. Zirkel in his Basaltgesteine * mentions the Edinburgh Castle rock, and the basalt which forms the summit of Arthur Seat, but microscopic investigation of the rocks of the Edinburgh district begins really with Allport's paper on "British Carboniferous Dolerites." † It is probable that before this time sections of some of the Arthur's Seat rocks had been prepared by Bryson,‡ following the methods of Witham, but if so no record of his observations is available at the present day. Allport gave descriptions of about twenty rocks from Mid-Lothian and West Lothian. He did not propose to subdivide them into groups, but called them basalts, porphyritic dolerites and coarsely crystalline dolerites; and considered that the Corstorphine Hill rock was a

* F. Zirkel, "Mikroskopische Struktur und Zusammensetzung der Basaltgesteine," 1870, p. 125.

† *Quart. Jour. Geol. Soc.*, 1874, vol. xxx. p. 529.

‡ Sir A. Geikie, "Founders of Geology," 1905, 2nd ed. p. 464.

gabbro. His main contention that there was no essential structural or mineralogical distinction between them and the dolerites and basalts of Tertiary age has now received universal acceptance.

The next contribution of importance to the petrography of the district is found in Sir A. Geikie's well-known paper on the Carboniferous volcanic rocks of the Firth of Forth basin. He adopts the following classification: (1) diabases, coarsely crystalline or granitoid; (2) dolerites, finely crystalline or crystalline granular, rarely porphyritic, often ophitic, and sometimes containing traces of a glassy base; and (3) basalts, with numerous phenocrysts in a fine groundmass.* He recognised that the Inchcolm rock, which had been described as resembling serpentine by Boué, was a typical picrite, and that a similar mass occurred at Blackburn. Many important features of the microscopic structure of these rocks were for the first time described by Sir A. Geikie, and his paper will be frequently referred to in this chapter.

Dr. Teall has given an account of the Carboniferous dolerites of Mid and West Lothian, which is partly based on the work of Allport and Sir A. Geikie, but contains also a number of new observations. Among these the most important are the occurrence of quartz hypersthene dolerite at Ratho, and of dolerite rich in analcite and approaching the teschenites (Carcraig). Both these types have proved to be abundant and well characterised in the area in question.†

In 1888 a paper by Dr. E. Stecher on the contact phenomena of the Scottish olivine-diabases appeared in Tschermak's *Mineralogische Mittheilungen*.‡ The material on which he worked had been collected by Sir A. Geikie, who placed it in the hands of Professor Zirkel at Leipzig. In this paper many of the best-known contacts in the district received detailed microscopic and chemical study, and the work of Hall, Sorby and Sir A. Geikie on this subject was confirmed and extended. In 1893 Mr. J. G. Goodchild identified the picrite mass associated with dolerite in Barnton railway cutting, and subsequently a paper by Mr. H. W. Monckton appeared, giving fuller details and microscopic descriptions of the minerals.§

The results of a revision of all the Carboniferous volcanic rocks of Central Scotland by Dr. F. H. Hatch were given in brief summary in Sir A. Geikie's presidential address to the Geological Society of London in 1892.‖ Dr. Hatch's work was continued by Professor W. W. Watts, who amplified and to some extent modified his classification, and Sir A. Geikie has made use of the revised grouping of the igneous rocks in his "Ancient Volcanoes."¶ The large collection of Carboniferous volcanic rocks from the Edinburgh and Linlithgow districts, made by Sir A. Geikie and the Geological Survey of Scotland and investigated by Dr. Hatch and Professor Watts, has been re-examined in preparation for this chapter, and the subdivisions laid down by these two petrographers will be adopted as far as seems desirable. Much new material has been forwarded by the

* *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. p. 437.

† J. J. H. Teall, "British Petrography," 1888, pp. 186 et seq.

‡ *Tschermak's Mineralogische und Petrographische Mittheilungen*, 1888, vol. ix. p. 145.

§ J. G. Goodchild, "Note on the Minerals Observed in the Railway Cutting at Barnton, near Edinburgh," *Trans. Geol. Soc. Edin.*, 1893, vol. vi. p. 301.

H. W. Monckton, "On a Picrite and other Associated Rocks at Barnton, near Edinburgh," *Quart. Jour. Geol. Soc.*, 1894, vol. l. p. 39.

‖ *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. Proceedings, p. 136.

¶ Sir A. Geikie, "Ancient Volcanoes of Great Britain," 1897, vol. i. pp. 417 et seq.

officers engaged in revising the maps and sliced for microscopic examination. The additional information gained has necessitated the introduction of certain supplementary groups.

If we exclude the picrites and mugearites, both of which are somewhat rare, the great majority of the post-Devonian igneous rocks of this sheet fall naturally into two fairly well-defined groups which have been recognised by practically all writers on the subject, namely, the non-porphyritic and coarse-grained dolerites and teschenites, and the porphyritic dolerites and basalts. The rocks of first group are all of intrusive origin and form the larger sills and laccolites together with the east and west dykes and many smaller intrusions. Glassy material is comparatively uncommon in the dolerites except at their chilled margins. They are rarely amygdaloidal; do not exhibit fluxion structure except along their edges, and weather usually in a well-marked spheroidal manner.*

As will be seen from the map, there are two groups of these coarsely crystalline dolerites (diabases) in this sheet, both occurring in considerable numbers and forming many large sills or laccolites. They are (1) the olivine dolerites and teschenites (with some rocks which may belong to the essexites) and (2) the quartz dolerites, which contain interstitial quartz and are typically free from olivine. The picrites are basic facies of the teschenites.

The porphyritic dolerites and the basalts form nearly all the lava flows and a limited number of the smaller intrusive masses in the district. They are not uncommonly amygdaloidal and fluidal, and when perfectly fresh the presence of a small amount of glassy base may often be established, but in the more coarsely crystalline types (dolerites), and when the rocks are decomposed, this cannot be traced. The phenocrysts are usually conspicuous in the hand specimens; but in the microscopic sections it is seen that the finely crystalline, or partly vitreous, groundmass is the main constituent. Porphyritic olivine is practically universal. Rocks of this group occur also as intrusive masses usually associated with lavas and tuffs; but intrusive and interbedded types cannot always be separated on the ground of microscopic character.

The Non-Porphyritic, Granular-Crystalline Dolerites (Diabases), Teschenites and Essexites.

I. Olivine dolerites, teschenites (analcite olivine dolerites) and essexites (with the picrites).

The rocks of this group are distinguished not only by the occurrence of olivine but also by many other peculiarities which render them recognisable even when the olivine has entirely decomposed. The chief of these are the purplish colour of the augite and its frequent zonal structure, the abundance of apatite, the frequent presence of reddish brown biotite. Furthermore analcite occurs only in this group.

The olivine forms rounded grains, not usually with crystal outlines. Very few of the rocks show this mineral in a fresh condition. It decomposes into green serpentine, and thereafter

* Sir A. Geikie, "Ancient Volcanoes of Great Britain," vol. i. p. 455.

into calcite and limonite. The augite is occasionally clear pale greenish brown, but usually has that purplish tinge which is supposed to indicate a considerable percentage of titanium. Zonal structure is not uncommon, but is far from universal. The margins are often purplish brown, while the centres are brown or greenish; hour-glass structure may at times be detected. Not unfrequently there is simple or repeated twinning on the orthopinacoid. Clear green and greyish green colours are also seen, but only rarely. The usual prismatic cleavage is, in a few cases, accompanied by another parallel to the orthopinacoid, as was remarked by Allport in the diabase of Corstorphine Hill. In polarised light the augite often yields blue and brown interference colours, owing to a marked dispersion of the optic axes, and this is more evident in sections perpendicular to the A axis than the B axis. The margins of the pyroxene crystals are occasionally green, apparently through decomposition, and in many rocks the augite is represented only by spherulitic or irregular aggregates of chlorite, with calcite and sometimes epidote; uralitisation is distinctly rare.

Biotite in dark chestnut-brown scales, changing to pale brown when the polariser is rotated, is very widespread in the olivine dolerites, but does not occur abundantly in any of them. It is most commonly adherent to the surface of irregular crystals of titaniferous iron oxide. Brown hornblende appears occasionally in some rocks, as at Inchcolm, Barnton and Whitehouse Point, but is much less frequent than biotite.

The felspars are of two kinds, plagioclase and orthoclase. The plagioclase has the typical broad or narrow lath-shaped outlines characteristic of the dolerites. They are twinned on Carlsbad, albite and pericline plans and belong for the most part to bytownite and basic varieties of labradorite. Occasionally they are zoned, though this is not pronounced, and a narrow outer portion may show transitions to andesine and oligoclase. In many of the teschenites orthoclase occurs. It is simply twinned or untwinned and has a streaky or patchy character between crossed nicols which indicates that it is rich in soda. Here and there a regular microperthite structure may be seen. It weathers in a different way from the soda-lime felspar, and has a lower refractive index and double refraction. Many of the slides contain only a very small amount of orthoclase, while in other rocks and other portions of the same rock it is very conspicuous in the sections. Where it surrounds plagioclase the zone which separates it from the basic cores may be much decomposed, and the fresh appearance of the orthoclase, especially where it adjoins miarolitic cavities, suggests that it may be partly secondary.

The iron oxides are usually titaniferous magnetite, in small octahedra and in large open networks or skeleton crystals. Apatite is very common in long hexagonal needles of considerable size. They often have a central cavity. Calcite, chlorite and analcite are the principal secondary products, with leucoxene, limonite, pyrites and serpentine. Epidote and uralite are rare. Zeolites are very frequent and occasionally, where decomposition is advanced, secondary quartz makes its appearance.

Olivine Dolerites.—One of the best known and freshest olivine

dolerites of this sheet is that of Dalmahoy and Kaimes Hill which has been described by Allport, Sir A. Geikie and Dr. Teall.* It contains many small grains of olivine, mostly represented by green patches of serpentine with small fragments of the undecomposed mineral in their midst. The augite is of a pale brown colour, not usually zonal or dichroic. It is partly euhedral and partly encloses lath-shaped felspars in ophitic fashion. The felspar, which takes the form of short prisms, is mainly a basic variety of labradorite, near bytownite, with narrow, more acid marginal zones. Orthoclase is absent or can be present only in very small amount. The other ingredients are apatite and small grains of titaniferous iron oxide. The structure of this rock, as indicated above, is partly ophitic, but the augite is not abundant and there are extensive patches of finely crystalline interstitial material. These are more felspathic than the rest of the rock and consist of chlorite and small prisms of felspar which are often imperfect or brush-shaped. They may also occur as plumose outgrowths on the ends of the larger felspars of earlier formation. The iron oxides in these interstitial areas are minute, dust-like granules and plates. Analcite has not been observed in any slides of this rock, but in specimens from Hannahfield there is a very little interstitial quartz, which may, however, be secondary. In the Hannahfield quarry, also, specimens may be obtained in which the interstitial material is a perfectly fresh, brown glass, containing skeleton crystals of felspar, acicular prisms of augite and grains of iron oxide.

In its petrographical characters the Dalmahoy sill is not very closely related to any other rock of the same group in this sheet. Most of the olivine dolerites which are within a few miles of it are much decomposed, but contain analcite and present other features which link them with the teschenites. In Sir A. Geikie's paper a coloured figure of a slide of the rock is given.

Near Edinburgh there is a group of sills which present some features in common. They contain little or no analcite though zeolites are rather abundant in some specimens. These are the rocks of Corstorphine Hill, to the west of Edinburgh, and of Hawkhill and Lochend, between Edinburgh and Leith. Specimens from Corstorphine Hill Quarry have been frequently described; the rock is a diabase, much decomposed; it shows pseudomorphs after olivine, brown augite (fresh or altered into chlorite) and more or less weathered felspar. Ophitic structure is usually well marked in the rock slides. Analcite is absent, but zeolites occur, especially in veins in the rock. Titaniferous iron oxides, needles of apatite and a little biotite are also present. This diabase is so much decomposed that it does not invite minute description.

In its northward extension the Corstorphine Hill sill is intersected by the railway cutting near Barnton Station. In this locality, as has been described by Goodchild, Mr. H. W. Monckton and Sir Archibald Geikie, the mass consists principally of picrite with veins and smaller sills of diabase. The rock at the west end of the cutting is a coarse ophitic diabase, very similar to that of Corstorphine Hill,

* S. Allport, *Quart. Jour. Geol. Soc.*, 1874, vol. xxx. p. 555. Sir A. Geikie, *Trans. Roy. Soc. Edin.*, 1879, vol. xxix. p. 518. J. J. H. Teall, "British Petrography," 1888, p. 190.

but containing a little more biotite. The augite is fresh, but the felspars are much decomposed. The smaller intrusions to the east of the main mass belong to a peculiar type, rich in biotite, and have been described by Mr. Monckton as mica-porphyrites. They are comparatively fine grained with a slight tendency to porphyritic character owing to the presence of larger crystals of felspar and augite. In the hand specimens some of them show white spots which prove in the sections to be areas rich in zeolites. Presumably these rocks contained olivine, though this is only an inference drawn from the shapes of certain green pseudomorphs which may represent that mineral. The augite is purplish brown and very often is penetrated by felspar prisms in an ophitic manner, though eumorphic crystals also occur. A dark brown variety of biotite, biaxial but with small axial angles, is an important ingredient, and usually is attached to the surface of the titaniferous iron oxides. The latter seem to be mostly ilmenite, in flattened or fenestrated scales. The most peculiar feature of these rocks, however, is the nature of the felspars. These form small, imperfectly shaped prisms, which may be embedded in the augite but mostly build up a hypidiomorphic matrix. In the finer marginal facies there are small phenocrysts in subparallel fluxion arrangement. The felspars are either orthoclase or polysynthetic plagioclase, which from its low refractive index and small angles of symmetrical extinction belongs to oligoclase and oligoclase-albite. The latter is never idiomorphic but crystallises in irregular plates between the plagioclase crystals.

Essexites.—The Hawkhill and Lochend sills have much affinity with the smaller intrusions at Barnton. These are on the whole fine grained, though in both cases the sills are complex and seem to be made up of successive intrusions of which the later brecciate the earlier and show chilled edges against them. There is no pronounced porphyritic character, and the pale brown augite is partly ophitic and partly eumorphic. Dark brown biotite in small scales clinging to the iron oxides is a frequent ingredient. At Hawkhill there is a spotted variety with white patches about an eighth of an inch across, exactly similar to the spotted rocks from Barnton, above described. These spots are full of decomposition products and probably contain granular, doubly refracting analcite. At Barnton they consist of zeolites; in neither case do they show any crystalline form though their rounded shapes might suggest leucite. At Hawkhill and Lochend the prevalent felspars again are acid, and basic plagioclase is wanting; they are oligoclase and oligoclase-albite in elongated imperfect prisms with a little interstitial untwinned or simply twinned orthoclase. There is no fresh olivine in these rocks, and it is very doubtful whether this mineral was originally present as no characteristic pseudomorphs after it can been recognised.

The relationships of the Corstorphine, Barnton, Lochend and Hawkhill masses to the teschenites of this sheet are obscure. No teschenitic facies are developed at any of these localities; analcite is absent or very scarce; olivine may be present or absent; the augite has not the full purple colour nor the marked dispersion of the axes seen in that of the teschenites. It is probable that these are a closely related group, but not identical with the teschenites, and their chief distinguishing feature is the occurrence of acid

plagioclase and orthoclase in place of basic plagioclase, orthoclase and analcite. Their natural affinities seem to be with the essexites. A chemical analysis of the Lochend rock was prepared by Mr. E. G. Radley, and is given below with those of other essexites for comparison. Analysis III. represents an essexite from Craigleith, near North Berwick, which has been described in the memoir on East Lothian by Mr. E. B. Bailey. In some respects it is more typical than the Lochend rock as it contains a higher amount of alkalies and notably more potash. It is also in better preservation, as may be seen from the percentages of water and carbonic acid stated in the analysis. This essexite from East Lothian belongs also to an area in which teschenites, analcite dolerites and olivine dolerites are present.

	I.	II.	III.
SiO_2	48·63	50·50	47·03
TiO_2	2·04	1·91	2·64
Al_2O_3	15·03	17·64	15·36
Fe_2O_3	0·51	5·41	3·38
FeO	9·55	4·02	7·35
MnO	0·20	—	0·14
(CoNi)O	nt. fd.	—	trace
BaO	0·04	—	0·08
SrO	nt. det.	—	0·05
CaO	5·95	7·91	8·47
MgO	6·34	3·33	5·10
K_2O	0·56	3·02	3·00
Na_2O	5·32	5·52	4·32
Li_2O	trace	—	nt. fd.
H_2O (105°)	0·93	0·45	0·22
H_2O (above 105°)	3·16	—	2·60
P_2O_5	0·34	0·92	0·73
FeS_2	0·44	—	—
CO_2	1·12	—	nt. fd.
Total	100·16	100·63	100·67

I. Essexite, Lochend (11390), near Edinburgh (Anal. Mr. E. G. Radley).
II. Essexite, Rongstock, Bohemia.
III. Essexite (11897), Craigleith near North Berwick (Anal. Dr. W. Pollard), with S 0·08, Cl 0·04 Cr_2O_3 0·02, V_2O_3 0·03, ZrO_2 0·03.

Teschenites (*Analcite Olivine Diabases*) (Plate III. Fig. 1).—From their frequency and wide distribution the teschenites are of great importance in the district between Edinburgh and Linlithgow. They occur also on the north side of the Firth of Forth, near Charlestown. Mr. Stenhouse and Mr. Campbell have investigated the Inchcolm teschenite and its variations.* Similar rocks from Gullane in East

* R. Campbell and A. G. Stenhouse, "The Geology of Inchcolm," *Trans. Edin. Geol. Soc.*, 1908, vol. ix. p. 121. Rocks of this class occur also among the Carboniferous strata of the West of Scotland, and have been described in the following papers: J. D. Falconer, "The Geology of Ardrossan," *Trans. Roy. Soc. Edin.*, 1907, vol. xlv. p. 601. P. Macnair, "The Intrusive Dolerites in the Neighbourhood of Glasgow," *Trans. Geol. Soc. Glasg.*, 1907, vol. xiii. p. 56, and "Notes on a Dolerite showing Ocellar Structure, from Craigie Hill, Ayrshire," *op. cit.*, 1908, p. 235. Robert Boyle, "The Occurrence of Ultra-basic Rocks in the Igneous Intrusions of the Lugar and Cumnock Districts," *op. cit.*, 1908, p. 203.

Lothian have been described by Professor R. B. Young * and there are also examples of them in the east of Fife, near Anstruther.†

These rocks are always holocrystalline and usually rather coarse grained. Although very often the augite is penetrated by lath-shaped sections of felspar, so that the structure is partly ophitic, it is equally common to find the pyroxene mostly in idiomorphic crystals. In some of the finer grained rocks there is a tendency to the development of porphyritic structure, owing to the presence of larger crystals of euhedral plagioclase and augite. Olivine is probably always an ingredient of these rocks though it is never preserved, and its original presence can only be inferred from the shapes of its pseudomorphs. Purplish brown augite, with marked dispersion of the optic axes, is constantly present and is very characteristic of these teschenites. It is distinctly pleochroic, and often shows zonal and hour-glass structures. The early felspars are bytownite and basic labradorite, passing near their edges into andesine and oligoclase. Orthoclase, apparently rich in soda, appears in varying quantities in different rocks and in different specimens of the same rock. In narrow bands it surrounds the earlier formed plagioclase, and it may also occur in broad, simply twinned crystals which form patches in the rock containing a central, irregular area of analcite. These closely resemble the miarolitic spaces of certain granites, as there has been a progressive crystallisation from the outskirts to the centre of the area. Around them lies the ordinary rock matrix consisting of iron ores, olivine, augite and basic plagioclase. The orthoclase may show idiomorphic terminations where it impinges on the analcite, but frequently it has ragged, indefinite borders, or occurs in quite shapeless masses among the analcite and looks like a secondary mineral. There are other cases in which perfectly shaped crystals of clear alkali felspar appear among analcite and chlorite, while more rarely this water clear felspar is in hollow or imperfect forms.

Biotite, of rich brown colour and strong pleochroism, is found in many of the teschenites, but only in small amount. It is nearly uniaxial. Hornblende is much less common, being absent from the great majority of these rocks. It is confined to a few facies, rich in analcite, and to certain pegmatites or segregation veins. It is always of a dark brown colour. With the augite it forms parallel growths, the amphibole being usually external; they have the prism zone and the plane of symmetry in common. Other crystals of hornblende are free from augite; they are short or elongated prisms with the characteristic cross-section of amphibole; the extinction angle (Z : c) seems to be about 12°. The pleochroism of the hornblende in the teschenite of Whitehouse Point is Z dark brown, Y paler brown, X clear yellow (absorption $Z > Y > X$).

The analcite may be pellucid and nearly free from enclosures, or turbid and semi-opaque. Though often isotropic, it frequently shows anomalous double refraction, giving dark grey tints in polarised light. It may show cleavage distinctly, especially in the thinnest parts of the slides. In some rocks the place of analcite is filled with

* Young, R. B. An analcite diabase and other rocks from Gullane Hill, *Trans. Edin. Geol. Soc.*, 1905, vol. viii. p. 326.

† "Geology of East Fife," *Mem. Geol. Sur.*, 1902, p. 392.

clusters of radiate prismatic zeolites, and it is possible that these may sometimes have formed from the decomposition of analcite. Heddle * records the occurrence of pseudomorphs of pectolite after analcite in cavities in the quartz dolerite of Ratho.

The analcite is never idiomorphic except where it occurs in cavities and veins along with secondary minerals such as chlorite and carbonates. Its usual mode of occurrence is as an interstitial material filling up angular spaces between the other elements of the rock. The boundaries of these spaces are often formed by orthoclase, but in other cases by plagioclase or biotite. The primary minerals, which occur in the spaces with analcite, are apatite, felspar and biotite; augite and iron oxides are seldom seen in the analcite. The apatite and plagioclase are needles or elongated prisms which penetrate the analcite to some distance. Orthoclase occurs as broader prisms, which may be idiomorphic or irregular where they abut against the analcite, or may form shapeless areas within it. Analcite occurs also as an undoubtedly secondary mineral, filling cracks in plagioclase and orthoclase felspar, and easily recognised by its isotropic character and low refractive index. In nearly all the teschenites this phenomenon appears, and often a large part of the plagioclase is replaced by analcite. Indeed, instances are not uncommon in which the early plagioclase, which penetrates augite and produces ophitic structure, is represented only by lath-shaped sections of analcite, more or less turbid and mixed with secondary products.

The origin of the analcite of the teschenites has often been discussed. In the teschenites of Arran † Professor Corstorphine regarded it as secondary after nepheline, but Mr. Harker ‡ thinks it is primary. Professor Young § holds that in the teschenite of Gullane Hill it is most probable that the analcite is secondary after felspar. The same difficulties of interpretation have arisen with regard to the Moravian teschenites described by Rohrbach ‖ and Rosenbusch and the Portuguese rocks of this class which were studied by Macpherson.¶ In recent years new light has been thrown on this problem by Professor Lacroix's ** discovery of fresh nepheline in teschenites from Madagascar and Portugal, and in the well-known teschenite ("olivine dolerite") of Crawfordjohn in Lanarkshire. This proves that some of these rocks at any rate contain this mineral. Rosenbusch †† has also found nepheline in the Moravian teschenites.

These nepheline-bearing teschenites are post-Carboniferous; the Edinburgh teschenites are presumably Carboniferous and in accordance with their greater age they are more decomposed. Nepheline has not been detected in any of them, and there is not much hope that it will yet be found. From the evidence above given in

* Heddle, M. F., *The Mineralogy of Scotland*, 1901, vol. ii. p. 32.
† Corstorphine, G. S., *Tschermak's Min. Pet. Mittheil.*, 1895, vol. xiv. p. 443.
‡ Harker, A., *Mem. Geol. Sur.*, North Arran, etc., 1903, p. 113.
§ Young, R. B., *Trans. Edin. Geol. Soc.*, 1905, vol. viii. p. 331.
‖ Rohrbach, C. E. M., *Tschermak's Min. Pet. Mittheil.*, 1886, vol. vii. p. 1.
¶ Macpherson, J., *Commun. da Commissao do Trubalhos Geologicos de Portugal*, 1883, vol. i. p. 89.
** Lacroix, A., *Comptes Rendus*, 1900, vol. cxxx. p. 127.
†† Rosenbusch, H., *Mikroskopische Physiographie*, 1907, vol. ii. pt. i. p. 431.

reference to pseudomorphs of analcite after felspar it is clear that much, if not all, of this mineral is secondary. This conclusion is necessitated also by the frequency with which the analcite encloses chlorite and carbonates. The chlorite of these rocks, at any rate, is no longer regarded as primary. It often occurs in beautiful vermiform growths embedded in transparent analcite.

At the same time, however, there seems no reason why part of the analcite might not have been primary in a sense, that is to say the last product from a magma which was becoming progressively richer in vapours as crystallisation proceeded; the early minerals containing very little of the elements of water in their composition. This view has been advocated by Pirsson * and by Pelikan.† The experimental work which has been carried out by various scientists on analcite has led Doelter ‡ to conclude that it cannot have formed at temperatures higher than 500°. On this supposition it becomes very closely allied to the post-volcanic or pneumatolytic components of rocks, to which many of the zeolites belong. The Edinburgh teschenites do not furnish evidence likely to be conclusive on this point. Much of the analcite is clearly secondary, and from the way in which it replaces bytownite there seems good reason to believe that secondary processes have led to an enrichment of these rocks in soda. The remainder may be "primary" or secondary, and if secondary is more likely to have formed from nepheline and sodalite than from felspar.

The best known of the teschenites of this sheet is that of Salisbury Craigs; it is much decomposed, the olivine being replaced by serpentine, while the augite and felspar also are never entirely fresh. Biotite occurs in small quantity and there is a limited amount of alkali felspar. Analcite varies in abundance and many of the interstitial spaces are filled with calcite, chlorite and secondary quartz where the rock is much decomposed. The augite has a purplish colour and marked dispersion: the structure is partly ophitic and partly idiomorphic. Another teschenite occurs in the suburban railway cutting near Craiglockhart Station. It is very similar to that of Salisbury Craigs. Some of the sections of these rocks show well the permeation of basic plagioclase by veins of secondary analcite. This is still better seen in the small sill which outcrops on the shore to the east of the mouth of the Almond River. Many specimens from this locality have their felspar entirely replaced by analcite and other secondary products, while the outlines of the original crystals are still preserved and the ophitic relations to the augite are also clear. The abundance of biotite in this rock is unusual, but in this respect it resembles the small teschenite sill which lies to the west of Cramond. There is sometimes a good deal of untwinned or simply twinned orthoclase (rich in soda) in these rocks, and it may be much fresher and less infiltrated with analcite than the plagioclase. The augite is of a rich purple colour and has a strong dispersion.

A large and important teschenite sill occurs in Dalmeny Park forming Mons Hill and reaching the sea at Whitehouse Point

* *Bulletin U.S. Geol. Survey*, 237, Highwood Mountains, 1905, p. 155.
† Pelikan, A., *Tschermak's Min. Pet. Mittheil.*, 1906, vol. xxv. p. 113.
‡ Doelter, C., *Tschermak's Min. Pet. Mittheil.*, 1906, vol. xxv. p. 97.

(Plate XI. Fig. 1). The rock from Crossall Hill, described and figured by Sir Archibald Geikie, seems to come from this mass near its south end, where it is quarried beside the road to South Queensferry. Other outcrops of teschenite surround this one, at Craigie, Craigbrae, Dundas Castle, Lindsay's Craigs and Winchburgh. Some of these rocks are in very fair preservation, while others are much decomposed. They all contain augite of purple colour; biotite is much less common and hornblende appears only at Whitehouse Point. The prevailing felspar is bytownite and labradorite, but much orthoclase or anorthoclase appears in some of the specimens. It forms broad, simply twinned crystals, and its presence was remarked by Sir Archibald Geikie, though it was subsequently discredited by Dr. Stecher's observations. The microscopic sections contain much apatite in large long prisms, and reticulate or skeleton octahedra of titaniferous magnetite which are often coated with scales of dark brown biotite. Small crystals of plagioclase are often enclosed in the pyroxenes. Analcite varies considerably in abundance but is never absent; in some rocks groups of radiate acicular zeolites fill its place.

The rock of Whitehouse Point is the most typical teschenite of this district, if we accept the definition of that term which was formerly current, as it contains much dark brown amphibole and is not ophitic. Analcite is exceedingly plentiful in the specimens sliced, while the felspar is greatly decomposed, having been replaced by turbid analcite, mica and other secondary products, but calcite is by no means abundant. Here and there remains of basic plagioclase are visible, still showing their twinning and high refraction but everywhere surrounded and penetrated by analcite. Remains of olivine are scarce. The hornblende is dark brown and has the properties above described; it is mostly in parallel intergrowth with augite, but also occurs in separate individuals. A secondary amphibole of remarkable deep green colour is also present. Biotite is less frequent than hornblende and resembles it closely in colour and pleochroism. The other original ingredients of this rock are apatite and titaniferous magnetite. Calcite fills miarolitic spaces and chlorite also is fairly common.

The association of non-ophitic teschenites, rich in hornblende, with partly ophitic types in which hornblende is absent, has been described from Moravia by Rohrbach. In this locality, however, they form parts of the same intrusive mass, the hornblende-bearing variety being a marginal facies not occupying any considerable area. An analysis of the Mons Hill teschenite is given below.

Another group of teschenite sills occurs in the Linlithgow and Bangour districts. The following instances may be cited: Wester Ochiltree, one and a half miles south of Wester Ochiltree, Mochrie's Crag and Kingscavil. The diabase which accompanies the leckstone or picrite of Blackburn is a much decomposed teschenite and is rather rich in analcite. These rocks contain no hornblende and usually little biotite. Many of them show a fair amount of orthoclase and they are often very rich in analcite. It increases with decomposition, replacing the felspars over considerable areas of the rocks, and these have sometimes a rounded outline, giving the hand

specimens a spotted character. This is well seen in the teschenite of Mochrie's Crag, and recalls the similar appearance presented by some specimens of the Hawkhill sill. Most of these intrusions are rather fine grained with idiomorphic augite, and not ophitic; in fact, they tend to have a finely porphyritic structure owing to the euhedral character of the plagioclase and pyroxene, while the analcite often resembles a colourless, turbid or transparent, isotropic groundmass.

Segregation or Contemporaneous Veins.—In all the diabases, teschenites and picrites of this sheet segregations may occur forming veins or irregular patches in the mass of the rock. They vary from less than an inch up to a foot or more in diameter, and often branch or form an anastomosing network. As a rule they do not show chilled edges and must have originated at a time when the mass had solidified but was still hot. They have much the same relationship to the rocks in which they occur as the pegmatites and aplites have to the granites. A certain connection exists between the composition of these veins and that of the rock which they intersect, and this is sufficient to show that they are not of foreign origin but come from the same magma. In the quartz dolerites they contain quartz; in the olivine dolerites and teschenites quartz is absent, but there is much alkali felspar, green augite, dark brown hornblende and biotite, though often no analcite.

Good examples of these veins are furnished by the diabase of Barnton railway cutting. Their mode of occurrence has been described by Sir Archibald Geikie.* They are pale in colour and consist mainly of felspar, which is often so much decomposed that its optical properties are obscured, but includes both orthoclase and plagioclase. The margin of one of these veins has a "comby" structure, being composed of long narrow felspar crystals which are perpendicular to the walls of the vein. By optical and specific gravity methods these were proved to be plagioclase (near andesine) and orthoclase. The latter mineral was abundant and evidently contained a considerable percentage of soda. The crystalline outlines of these felspars were very imperfect. Mixed with these are dark brown, bladed prisms of hornblende, idiomorphic in transverse section (110, 010) but with tapering or pointed ends. The pleochroism is X brownish yellow, Y chestnut brown, Z darker chestnut brown; Z : c about 10°. A few small grains of bright green pyroxene are also to be found in these veins but the usual purplish augite is absent. The spaces between the felspars are filled with radiate clusters of strongly polarising zeolites; sphene (probably secondary), titaniferous iron oxides and chlorite are also visible in the slides.

Irregular segregationary patches of similar character occur in the mass of the diabase. They contain more of the bright green diopside, which may form idiomorphic crystals: occasionally also much dark brown mica, which may be in parallel growth with the hornblende. It will be seen that while purple augite and olivine are common in the diabase their place is taken in these veins by brown hornblende and biotite, while alkali felspars, on the whole, are more abundant in the segregations than in the mass of the rock. All the minerals of

* "Ancient Volcanoes of Great Britain," 1897, vol. i. p. 450.

these veins, however, are found occasionally in the diabases and teschenites.

In the Inchcolm picrite and teschenite there are thick felspathic veins which consist of turbid, mostly untwinned, felspar (largely a perthitic orthoclase), purplish brown and bright green idiomorphic augite and decomposition products. Brown hornblende was not seen in any of the slides.*

	I.	II.	III.	IV.	V.
SiO_2	46·06	43·55	45·71	46·77	48·18
TiO_2	2·56	2·48	1·64	2·31	—
Al_2O_3	15·94	14·84	15·23	14·91	11·80
Fe_2O_3	2·94	3·09	2·84	7·80	9·79
Cr_2O_3	—	—	0·02	nt. fd.	—
V_2O_3	—	—	0·03	0·02	—
FeO	7·44	7·44	6·93	4·90	5·90
MnO	0·31	0·23	·54	0·29	—
(CoNi)O	nt. fd.	nt. fd.	0·02	—	—
CaO	7·04	7·66	7·34	6·30	7·50
SrO	nt. fd.	nt. fd.	? trace	0·03	—
BaO	0·10	0·07	0·04	0·04	—
MgO	4·14	7·41	8·11	2·94	6·05
K_2O	2·76	1·90	1·31	2·37	1·57
Na_2O	4·95	3·82	3·96	4·97	3·46
Li_2O	? trace	trace	trace	trace	—
H_2O (105°)	·55	1·79	1·54	0·92	3·20
H_2O (above 105°) ..	4·22	5·08	4·70	4·28	—
P_2O_5	0·84	0·63	0·47	0·98	0·49
FeS_2	0·36	0·13	(S=0·08)	0·07	—
CO_2	0·11	0·53	—	trace	0·71
Cl	trace	nt. fd.	? trace	—	—
Total	100·32	100·65	100·51	99·90	98·65

I. Teschenite, Mons Hill (shore at Whitehouse Point), Dalmeny, Mid-Lothian (13437) (Anal. Mr. E. G. Radley).
II. „ Mochrie's Crag, Linlithgowshire (11894) (Anal. Mr. E. G. Radley).
III. „ "Leckstone" Quarry, Blackburn (11860), Linlithgowshire (Anal. Dr. W. Pollard).
IV. „ Mapleton Township, Maine (Anal. W. F. Hillebrand) (*Bull. U.S.G.S.*, 165, p. 183).
V. „ Boguschowitz, Silesia (Rosenbusch, "Elemente der Gesteinslehre," 2nd ed. p. 182).

From these analyses it will be seen that the teschenites of the Lothians, in spite of their variations in structure, have a remarkably uniform chemical composition. For basic rocks they are rich in alkalies, especially the teschenite of Mons Hill. Moreover they resemble closely the essexites above described, the only noteworthy differences being that the latter contain more alkalies and less lime. As will be shown later the teschenites have close relationships to the picrites of this area, both in field occurrence and in petrographical characters. Consequently there is no room for doubt that these three groups of rocks in the Mid-Lothian district are representatives of the same magma.

* R. Campbell and A. G. Stenhouse, *loc. cit.*

Picrites (Plate XI. Fig. 2).—No new occurrence of picrite has been added to those already known* by the resurvey of the area included in this sheet. They are the Inchcolm picrite, the Bathgate "leckstone" and the picrite of Barnton. They differ from the teschenites and diabases with which they are associated only in the scarcity of felspar and greater abundance of olivine and augite. Brown hornblende and reddish brown biotite occur in most of them, and their structure is sometimes rather coarsely poikilitic. In the field they are easily recognisable by their dark green colour and ready decomposition.

Of these the Inchcolm picrite is the best preserved and, from the descriptions of Sir A. Geikie, Professor Judd and Dr. Teall, is one of the best known of British picrites. It contains brown hornblende, in addition to augite, and often in parallel growth with it. There is also some biotite in the rock, and remains of weathered felspar. A coloured plate of it appears in Dr. Teall's "British Petrography" (Plate VII.).

	I.	II.	III.
SiO_2	45·71	44·73	37·8
TiO_2	1·64	1·53	—
Al_2O_3	15·23	11·89	9·7
Fe_2O_3	2·84	4·85	3·4
Cr_2O_3	0·02	0·05	—
V_2O_3	0·03	0·03	—
FeO	6·93	6·61	7·0
MnO	0·54	0·41	—
(CoNi)O	0·02	0·03	—
CaO	7·34	7·69	4·1
SrO	? trace	? trace	—
BaO	0·04	0·03	—
MgO	8·11	10·77	22·9
K_2O	1·31	0·89	0·8
Na_2O	3·96	2·77	
Li_2O	trace	? trace	—
$H_2O-105°$	1·54	3·49	14·0
$H_2O+105°$	4·70	4·15	
P_2O_5	0·47	0·46	—
S	0·08	0·05	—
Cl	trace	nt. fd.	—
Total	100·51	100·43	—

I. Teschenite, "Leckstone" Quarry, Blackburn, Linlithgowshire (11860) (Anal. Dr. W. Pollard).

II. Picrite ("leckstone"), same locality (11859) (Anal. Dr. W. Pollard).

III. Picrite, Inchcolm (Judd, *Quart. Jour. Geol. Soc.*, 1885, vol. xli. p. 400).

* Sir A. Geikie, "Carboniferous Volcanic Rocks of the Firth of Forth," *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. p. 504. Cole's "Studies in Microscopical Science," 1882. J. W. Judd, "Tertiary and Older Peridotites of Scotland," *Quart. Jour. Geol. Soc.*, 1885, vol. xli. p. 400. J. J. H. Teall, "British Petrography," 1888, p. 94. J. G. Goodchild, "Minerals Observed in the Barnton Cutting," *Trans. Edin. Geol. Soc.*, 1893, vol. vi. p. 301. H. W. Monckton, "On a Picrite and Associated Rocks at Barnton," *Quart. Jour. Geol. Soc.*, 1894, vol. l. p. 39. Sir A. Geikie, "Ancient Volcanoes of Great Britain," 1899, vol. i. R. Campbell and A. G. Stenhouse, *loc. cit.*

The Bathgate picrite has been described and figured by Sir Archibald Geikie in his paper on the Carboniferous volcanic rocks of the Firth of Forth. This rock is more decomposed, contains less hornblende and biotite, but is rich in analcite and weathered felspar; in fact, it shows close relations to the teschenite which occurs along with it. The Barnton picrite has been described by Mr. H. W. Monckton and the late Mr. J. G. Goodchild. It contains a little dark brown biotite and secondary products after felspar (Plate XI. Fig. 2).

The analyses of the teschenite and picrite of Rusha Quarry, Blackburn, given on page 300, show that the picrite is merely a basic segregation from the teschenite and contains somewhat less alkalies and alumina but more magnesia and iron. The Inchcolm picrite, on the other hand, from Professor Judd's analysis, approximates more closely to the true ultrabasic type.

II. QUARTZ DOLERITES (QUARTZ DIABASES).

The rocks of this group are more frequent in the area under description than the olivine dolerites and teschenites. They occur not only as large sills but also as dykes. In the hand specimen it is sometimes impossible to say to which of these classes a specimen belongs, but quartz and reddish areas of micropegmatite may sometimes be detected in the quartz dolerites. Coarse-grained and moderately fine-grained types are both common.

The quartz dolerites (quartz diabases) of the Bathgate and Linlithgow Hills have recently been fully described by Dr. John Falconer.* They are very similar in most respects to those which occur throughout the counties of Edinburgh and Linlithgow, and the results of our investigations do not differ from those he has arrived at except in unimportant points. His paper is accompanied by a useful series of analyses of these diabases and their modifications.

The presence of quartz in the Carboniferous dolerites of Scotland was noted by Allport,† especially in the North Queensferry sill; he regarded it as in all cases secondary. Sir Archibald Geikie was of the same opinion.‡ Dr. Teall,§ in his investigation of the Ratho rock, first established its primary nature. Dr. Stecher‖ observed the presence of quartz in the Hound Point and other sills. Mr. Monckton¶ found quartz in the Stirling dolerite, but was doubtful whether it should be regarded as an original ingredient; this rock also contains hypersthene. Quartz dolerites have been described from Arran by Professor Corstorphine** and Mr. Harker,†† but these are of Tertiary age. They show, however, many of the essential features of those of the Lothians. Representatives of this group occur also in the east of Fife.‡‡ Probably they are abundant through the whole

* Falconer, J. D., "The Igneous Geology of the Bathgate and Linlithgow Hills," Part II.—"Petrography," *Trans. Roy. Soc. Edin.*, 1906, vol. xlv. pt. i. p. 133.

† *Quart. Jour. Geol. Soc.*, 1874, p. 547.

‡ *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. p. 491.

§ "British Petrography," 1888, p. 190.

‖ *Tschermak's Min. Pet. Mittheil.*, 1888, vol. ix. p. 162.

¶ *Quart. Jour. Geol. Soc.*, 1895, pp. 490–491.

** *Tschermak's Min. Pet. Mittheil.*, 1895, vol. xiv. p. 443.

†† "Geology of North Arran," *Mem. Geol. Sur.*, 1903, p. 111.

‡‡ "Geology of East Fife," *Mem. Geol. Sur.*, 1902, pp. 190 and 391.

of the central valley of Scotland. Excellent examples have been described from Dumbartonshire by Mr. Tyrrell.*

A few coarse dolerites, which apparently contain no olivine and little if any primary quartz, are known from this area, but none of them is in a satisfactory condition. It is probable, however, that all the olivine-free dolerites of this sheet are related to the quartz dolerites. On the other hand, some of the quartz dolerites may contain olivine, but this is only at their margins and in the smaller dykes and sills. In the interior of the sills it seems to have been resorbed, if it was originally present, and hence it may be regarded as a non-essential mineral. In no case has the olivine been found in a fresh condition; there are many cases in which pseudomorphs occur in the quartz dolerites which may possibly have formed after olivine but are not sufficiently characteristic to render this certain.

Although some of the quartz dolerites have ophitic structure very well developed, the great majority of the rocks of this class are intersertal (Plate IX. Fig. 3). Very frequently in the same rock the augite may enclose a part of the felspar, yielding ophitic structure, while in other places the pyroxene is highly idiomorphic. This is especially marked in those rocks which contain much mesostasis; the augite is ophitic where in contact with the felspar but idiomorphic where surrounded by groundmass. This feature was noted by Professor Watts in his description of the "Bowden Hill" type of doleritic basalts,† and has been remarked also by Dr. Falconer. It is impossible to divide this group into ophitic and non-ophitic classes, as both types of structure may be found in different parts of the same slide.

A tendency to porphyritic character occurs in some of these rocks. It is partly due to the presence of idiomorphic crystals of pyroxene (both rhombic and monoclinic) but more particularly to the frequency with which the interstitial groundmass increases in amount so greatly as to become an important portion of the rock. As a rule it is not more than a sixth, but it may form quite one-half of the mass, and Dr. Falconer notes that in exceptional cases the matrix may amount to 70 per cent. of the whole rock. This porphyritic structure, however, is rarely obvious in the hand specimens and does not mask the granular character of the whole series.

When the rocks decompose the intersertal mesostasis tends to be filled with calcite, chlorite and secondary quartz; and this, combined with its fine-grained structure, often renders it impossible to say what minerals enter into its composition. But a study of the fresher rocks renders it certain that very frequently primary quartz is present as the last product of consolidation. Usually it is intergrown with an untwinned felspar to form a very fine micropegmatite (Plate IX. Fig. 3). In many sections this has a pseudospherulitic structure precisely like that of many granophyres. Delicate fibres of this substance radiate outwards from the margins of the older felspars, and as the slide is rotated between crossed nicols a dark sector sweeps round

* G. W. Tyrrell, "The Petrology and Intrusions of the Kilsyth-Croy District," *Geol. Mag.*, 1909, pp. 299 and 359.

† Sir A. Geikie, "Ancient Volcanoes," 1897, vol. i. p. 418. The Ratho type and the Bowden Hill type of dolerite, recognised by Professor Watts in his classification, are here regarded as the same; both are quartz dolerites which may contain rhombic pyroxene; they differ only in the relative proportion of mesostasis. The Binny Craig type is an exceptional facies of the quartz dolerites.

the aggregate. By this property its nature becomes clear even when high powers cannot resolve it into its ingredients. In other cases even with low magnifications little angular quartz grains can be seen lying in a matrix of turbid felspar. Each mineral extinguishes uniformly over a considerable area, and a radiate structure is not visible or is very imperfectly developed (micrographic type). Another variety consists of small rectangular felspars with grains of quartz between them, apparently not in optical continuity with one another (microcrystalline). When quartz, however, is fairly abundant it tends to form large irregular grains, in the edges of which little felspars are embedded. The structure is then micropoikilitic, but it is probable that these patches of quartz when they attain considerable size are mainly secondary. The formation of quartz in the interstitial spaces has continued to a late period in the consolidation of the rock, and it is very difficult to form an opinion how much of it is to be taken as primary. The secondary quartz appears as a mosaic of large grains with calcite, chlorite, kaolin, mica, iron oxides and pseudomorphs after small felspars. The occurrence of quartz as pseudomorphs after hypersthene, augite and other minerals makes its secondary nature in many instances indisputable.

There are other rocks which have a mesostasis in which quartz is very scanty and in all probability secondary. A turbid brown or grey substance then makes its appearance, which is probably a felsite or a devitrified glass. Iron oxides, brown stains of limonite, calcite, chlorite and other decomposition products commonly obscure its optical characters. It is essentially cryptocrystalline and the felspars which lie in it have often hollow or brush-shaped forms, and may radiate as long fibres from the surfaces of the earlier felspar crystals which surround the interstitial space. In a few rocks a pale brown glass containing small, dusty particles of iron oxide occurs, though never in great quantity; this is only in thin dykes and near the edges of the sills.

The augite of the quartz diabases is pale brown in colour, sometimes yellowish or brownish green. It never shows the purple tints so characteristic of the teschenites. It is rarely zonal, though sometimes it has central areas of darker and browner shade than the margins of the crystals; very seldom can hour-glass structure be seen in it. Pleochroism is not noticeable even in comparatively thick sections. Twinning on the orthopinacoid is very frequent and may be repeated. A fine basal lamination often appears, especially in the coarser-grained rocks, and when combined with simple twinning on the orthopinacoid yields a herring-bone structure. This lamination is often restricted to the centres of the crystals, while the edges are free from it (Plate IX. Fig. 5). It appears to be a primary feature of the pyroxenes in which it occurs, but it becomes more evident as decomposition progresses, because secondary products form readily along the basal parting of the crystals. In some rocks these central portions are traversed by dark lines which are divergent and may be curved; they are probably not due to a lamination but to enclosures or cavities in the mineral.

Two varieties of augite are common in these rocks. One of these is granular or equidimensional and, while often partly idiomorphic, at other times encloses much plagioclase in ophitic fashion. The

other forms long narrow prisms, which at any rate in cross section show large pinacoidal and small prismatic faces. Dr. Falconer has remarked that the latter kind may form branching growths of considerable size, visible easily in the hand specimens. He has found that some of them have a pleochroism resembling that of hypersthene, a feature noted by several writers in the augites of this series of rocks. Both of these types of augite may show basal lamination; the prismatic form is more readily decomposed than the other and is less often seen in a fresh condition. This is apparently the mineral which has so often been described as sahlite and is otherwise known as magnesium-diopside and enstatite-augite.* It has not, however, all the features of these augites. Its optic axial angle is small (2E is 70 and 71 degrees in the few specimens which I have been able to measure) but not so small or so variable as in the same mineral from other localities. The granular green augite, which occurs only in short prisms and irregular masses, has also a small axial angle for pyroxene (2E is 80 to 82½ degrees, and is fairly constant). Hence though both varieties have this property of the magnesium-diopsides to some extent they do not show them in so marked a manner as might have been expected. The extinction angle Z : c in both is about 42 degrees. The brownish variety of augite which forms cores to some of the granular crystals has a larger axial angle and a lower double refraction than the greenish brown augite of the exterior.

In decomposition these pyroxenes yield calcite, hornblende, mica, bastite and chlorite. Very often the resulting pseudomorphs are of mixed character, containing more than one of these secondary minerals in a felted aggregate, which cannot be analysed into its elements by the microscope. The hornblende is usually fibrous uralite with a pleochroism ranging from clear yellow to a dark shade of grass green. In some of the more weathered rocks the augite is almost entirely replaced by this mineral. The mica has colours which vary from pale yellow to deep green when the polariser is rotated, and is easily distinguished in the coarser aggregates by its straight extinction and strong double refraction. The chlorite is very similar in appearance to the secondary hornblende but has much lower polarisation colours. Calcite forms well-defined grains only in the last stages, when it is often accompanied by quartz. These secondary minerals appear not only in pseudomorphs but also in patches in the groundmass and the other components of the rock.

Rhombic pyroxene occurs in many of the quartz diabases (Plate IX. Fig. 4). It forms idiomorphic, elongated prisms with nearly square transverse sections in which the pinacoids predominate over the prism faces. The pleochroism varies, but is occasionally strong, in tints which range from pale green to salmon pink. For the most part it is weaker than this, and may be nearly absent. It may be fairly assumed that most of this mineral in these rocks belongs to hypersthene; all the sections which were perpendicular to an optic axis proved to be optically negative. In one slide taken from a specimen of the North Queensferry mass the rhombic pyroxene encloses plagioclase felspar, but with this exception it is always a very early mineral to crystallise. It has not been found intergrown

* Wahl, "Die Enstatit Augite," 1906.

with the monoclinic pyroxenes, though these, and also hornblende, may surround it in parallel growth. In by far the major part of its occurrences it is altered to bastite and a green, strongly pleochroic biotite.

Hornblende and biotite are not uncommon primary accessories, though they rarely occur in any considerable amount. Very often the augite is surrounded by brown hornblende of rather pale colour, in parallel growth. This hornblende is very rarely idiomorphic, but small prismatic crystals may be found occasionally in the quartzo-felspathic groundmass. On its outer surface a secondary growth of green uralite may occur like a fringe. Its pleochroism is X nearly colourless or faint yellow, Y cinnamon brown, Z clove brown. The angle $Z:c$ is about 12°. Primary biotite is much rarer than secondary; it has a deeper brown colour and stronger dichroism, and generally forms small imperfect hexagonal plates which may be adherent to the iron oxides. Both of these minerals are of later crystallisation than the pyroxene, as they frequently occur on its surfaces, but occasionally the hornblende is intergrown with the augite in scattered patches of indefinite outlines which extinguish simultaneously, and are in parallel growth with the pyroxene. It is not always possible to distinguish between the primary and secondary micas of these rocks.

The felspars are often very fresh, though in the more decomposed rocks they are stained with chlorite and contain much calcite, white mica and other secondary products. They are, however, as a rule, in a much better state of preservation than those of the olivine diabases and teschenites. A marked feature is their strongly zonal character (Plate IX. Fig. 3). Between crossed nicols it is obvious that their centres consist of a basic variety of labradorite with high angles of symmetrical extinction, while towards their margins they become progressively more acid and have smaller extinction angles. Bytownite occurs in the central parts of some crystals, but the greater part of the interior of the felspars has the composition of a medium or rather basic labradorite, while in a thin external zone the extinction angles and other properties change rapidly and there is an outer rim which has a straight extinction. This last is very frequently in optical continuity with the felspar of the interstitial micropegmatite. It is interesting to observe the diminishing refractive index when a broken zonal felspar abuts on the balsam in which the section is mounted. The latter has a refractive index very nearly the same as that of the ordinary ray in quartz. The central part of the felspar has a distinctly higher index than the balsam. Very near the outer edge the two substances have the same mean index, and here the felspar is oligoclase, but in the outer zone the balsam has higher index of refraction than all rays in the mineral.

In the micropegmatite the felspar is almost always cloudy and turbid, but is certainly in nearly all cases untwinned, though in a few slides small areas of polysynthetic felspar have been seen intergrown with quartz. Irregular patches of orthoclase appear sometimes in the micropegmatite and on the edges of the earlier felspars. To confirm these observations some of the rocks were powdered and placed in a heavy solution, in which albite sank while orthoclase floated. Those particles which did not sink were examined microscopically

and proved to have the refractive indices of orthoclase. This mineral is by no means abundant and is probably confined to the micropegmatite and perhaps also to the outer zones of the felspars. It may also be pointed out that the analyses given by Dr. Falconer show that some of these rocks contain over 2 per cent. of potash.

The quartz calls for no special description. Apatite is abundant in needles which sometimes have long central cavities. The iron oxides are titaniferous and include ilmenite and magnetite; they weather to leucoxene, and sometimes in the coarser rocks form large open networks.

Rhombic pyroxene occurs in prismatic crystals in many of the more important sills. Its presence in the Ratho dolerite has been known for some time; North Queensferry (Plate IX. Fig. 4), Craigie Hall, Carribber and Bowden Hill, West Bangour and Whitelaw (about one mile east of Bathgate) are other localities for quartz hypersthene diabase. It seems to have a predilection for the coarser rocks as we have not found it in any of the finer grained dykes and sills. It is so often decomposed, however, and in that state so much resembles the prismatic variety of augite that its presence may be suspected in very many instances where it can no longer be recognised with certainty.

The finer grained varieties of quartz diabase occur principally near the edges of the sills and in the smaller east and west dykes. They have been described by Dr. Falconer as diabase aphanites and correspond to the tholeiites of Dr. Hatch and Professor Watts. A number of features appear in these rocks which are peculiar to them and serve to distinguish the aphanites from the diabases. So far as is known they contain neither olivine nor hypersthene. Their augite is of the brownish green colour common in the diabases, but does not show the basal lamination (except very occasionally). While sometimes prismatic, the pyroxene is usually granular and has imperfect idiomorphism; it does not enclose felspar to any extent and the rocks are not ophitic. Very often calcite, chlorite and uralite have replaced all the augite. Biotite and hornblende of primary nature are very scarce. The felspars are mostly in lath-shaped crystals and have basic centres with acid margins as in the diabases. Iron oxides occur both in small octahedra and in reticulate skeleton growths which form rectangular lattices, and may spread through several square millimetres of a rock section. This last feature is very characteristic of the chilled edges of the rocks of this group, and has been described and figured by Sir Archibald Geikie.* The interstitial material is not usually very abundant and may contain much crystalline quartz in irregular grains; more often it is very fine micropegmatite of pseudospherulitic structure; a few of the slides contain interstitial brown glass. A good example of a rock containing vitreous base occurs in the railway cutting at Dalmeny, one mile south-east of Queensferry. The glassy material is full of globulites and beautiful feathery growths of green augite, with small prisms of felspar and grains of magnetite. Small cavities filled with quartz and chlorite are found in it also. The mesostasis of this rock strikingly resembles that seen in slides of the olivine dolerite from Hannahfield near Dalmahoy.

* *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. plate xii. fig. 12.

In these aphanites there is no fluxion structure; sometimes small porphyritic felspars and augites may be seen, but they are not conspicuous; steam cavities are common and are generally filled with calcite, chlorite and quartz. Another characteristic of these rocks is the abundance of rounded ocelli (Plate IX. Fig. 6) filled with a finely crystalline material consisting of radiate, brush-shaped felspars, reticulate skeletons of iron oxide and granules of augite; these are steam cavities occupied by the still liquid matrix at a time when the earlier minerals had crystallised but the groundmass had still to solidify. Their nature was first explained by Dr. Teall * and they have been figured and described by Dr. Falconer.† Where the occupation of the vesicle was not complete a cavity was left which was subsequently filled in with quartz and other secondary products.

[The large patches of glassy base described by Sir A. Geikie (Presid. Address Geol. Soc. 1892, *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. p. 132) as present in the Bowden Hill and North Queensferry sills have not been found in any slides of these rocks; they are probably fine micropegmatite.]

Segregation Veins.—In the quartz diabases acid segregation veins are of very common occurrence; a number of these can be very well seen in the railway cuttings between North Queensferry and Inverkeithing. They occur also at Ratho, Hound Point, Carribber, and in all the principal sills. Dr. Falconer has described those of the Linlithgow district and has given analyses.‡ They consist of acid plagioclase, orthoclase and quartz, and are often very rich in micropegmatite. As a rule they contain very little augite or other ferromagnesian minerals; their pyroxene is similar to that of the sills, but is perhaps more often in elongated prisms. As might be expected, these veins often show more primary hornblende and biotite than the main diabases, as the later elements of consolidation are more likely to be represented in them than the earlier. Though posterior to the diabases they belong to the same magma, and, as they have no chilled edges, it is probable that intrusion took place while the sills were cooling. A few of these veins show rudimentary fluxion structure, but the majority do not. Some of them are finely porphyritic; others are microcrystalline. They vary much both in composition and in structure, but the minerals they contain are always to be found in the diabases they intersect. These quartzo-felspathic veins are never found in the olivine diabases and teschenites, where the segregation veins, as already described, are of quite a different character.

Chemical Composition of the Quartz Diabases.—For information regarding the chemical composition of the quartz diabases of the Lothians we are indebted to Dr. Falconer, who has given analyses both of the sills and of their veins and other modifications. His results are quoted below, and show how great is the variation which one mass may present in these respects. The acid contemporaneous veins are far from resembling granites and porphyries in composition, while there is a very close relationship between them and the diabases they intersect. The great preponderance of soda over

* Teall, J. J. H., *Geol. Mag.*, 1889, p. 481.
† Falconer, J. D., *loc. cit.*, p. 148.
‡ Falconer, J. D., *loc. cit.*

potash is especially remarkable. The whole series shows also how with decrease in silica there is a corresponding diminution in the alkalies, while lime, magnesia and iron oxides (with titanium) increase in amount. The alumina, on the other hand, remains fairly constant. The margins of the sills would seem to be somewhat more basic than their centres, while the late segregation veins are most acid of all.

	I.	II.	III.	IV.	V.	VI.
SiO_2	48·02	59·33	56·22	51·80	64·54	71·26
TiO_2	3·36	3·42			1·22	0·28
Al_2O_3	13·03	12·86	16·33	16·43	13·63	11·87
P_2O_5	0·395	0·388			0·32	0·10
FeO	9·99	6·46	7·94	10·64	4·83	2·12
FeS_2	1·24	0·215	—	—	1·735	0·256
Fe_2O_3	2·11	1·88	3·11	1·20	0·22	0·10
MnO	trace	0·14	0·11	0·39	0·20	0·06
CaO	9·77	3·74	5·63	4·13	2·31	2·88
MgO	4·21	2·09	2·99	5·76	1·25	1·08
K O	0·49	2·15	1·65	0·85	2·28	0·054
Na_2O	2·17	5·13	3·84	3·81	5·81	6·73
SO_3	trace	—	—	—	trace	—
F	0·058	0·044	—	—	0·056	0·009
H_2O (comb.) / CO_2	4·27	2·12	1·63	3·89	1·86	2·71
Moisture	1·05	0·48	0·88	1·47	0·84	0·62
	100·16	100·44	100·33	100·37	100·50	100·12

I. Dark coloured modification, somewhat weathered, Kettlestoun Quarry.
II. Light coloured felspathic modification, Kettlestoun Quarry.
III. Interior of Carribber sill, Carribber Quarry.
IV. Ocellar margin of Carribber sill, Carribber Glen.
V. Blue band, Carribber Quarry.
VI. Red band, Carribber Quarry.

MARGINAL PHENOMENA OF THE DOLERITE SILLS.

The changes of texture that take place in the dolerite sills near their contact with the underlying and overlying sediments are sufficiently evident to the naked eye and have long been familiar to observers. The early Wernerians, following the example of their master, taught that a gradual transition from sediment to greenstone was normal in such situations; hence it is somewhat remarkable that neither Hutton nor Playfair adduced the fine grained chilled margins as proof of the igneous origin of the sills; Sir James Hall, however, remarking on the glassy selvages * of some of the dykes of Vesuvius, pointed out the explanation and insisted on its importance. Later writers, such as Allan,† Hay Cunningham,‡ Rhind § and

* Sir James Hall, "Experiments on Whinstone and Lava," *Trans. Roy. Soc. Edin.*, 1805, vol. v. p. 73.

† Robert Allan, "On the Rocks in the Vicinity of Edinburgh," *Trans. Roy. Soc. Edin.*, 1812, vol. vi. p. 416.

‡ R. J. Hay Cunningham, "Geology of the Lothians," *Mem. Wernerian Soc.*, 1838, vol. vii. p. 48.

§ William Rhind, "Excursions Illustrative of the Geology and Natural History of the Environs of Edinburgh" (2nd ed.), 1836, p. 14.

MacLaren,* give careful descriptions of the phenomena and had no doubt as to their significance, and even Ami Boué † saw how sharply defined were the margins of the dolerites, and scouted the idea of a passage from the one type of rock into the other.

Sir Archibald Geikie ‡ was the first to apply the methods of microscopical research to this problem so far as regards the Mid-Lothian sills, and he has given in several places an account of his observations. He also supplied the specimens on which Dr. Stecher's § fuller account of the phenomena are based. The marginal changes in the Stirling dolerite have been described by Mr. H. W. Monckton.‖

In most cases where the edges of the sills are exposed they are in an advanced stage of decomposition, and though they may contain fresh felspar and biotite, their augite and olivine are represented by pseudomorphs, and the whole rock is infiltrated with calcite, iron oxides, pyrites and chlorite. The actual margin for a distance of one or several millimetres is very dark and fine grained. Under the microscope it is usually decomposed and always cryptocrystalline, though there seems good reason to believe that it was once glassy. Between crossed nicols it depolarises the light as a very fine mosaic like the most fine-grained kinds of felsitic material. Its original state is indicated by numerous spots which resemble the spherulites so characteristic of the tachylyte selvages of basic dykes, but now only rarely show traces of spherulitic structure (see Plate X. Figs. 1 and 2, Plate XI. Fig. 6). This margin is filled with very minute rounded grains of iron oxide which give it a black colour and render it almost opaque; it would seem that there has been a slight concentration of the iron oxides in the chilled margin. When this black selvage is weathered it turns dark red. Pyrites, probably secondary, is often abundant in these situations. Excellent examples of these devitrified tachylytes are to be obtained at Salisbury Craigs, Hound Point, Auchinoon, Camps Quarry, Rosyth Castle and many other places.

At a distance of a millimetre or two from the contact the igneous rock is a porphyritic olivine basalt with cryptocrystalline groundmass. Veins two or three millimetres in thickness show this structure very clearly (see Plate XI. Fig. 6). The phenocrysts are as a rule not numerous; they always form the smaller portion of the whole mass, and they frequently have an orientation of their long axes parallel to the line of junction which is due to fluxion movements in the molten intrusive rock. Felspar, augite and olivine are the porphyritic minerals. The olivine is always decomposed, but its presence is usually rendered certain from the outlines of the pseudomorphs (which correspond usually either to small idiomorphic crystals or to imperfect growth forms of this mineral). Stecher ¶ made the

* Charles MacLaren, "A Sketch of the Geology of Fife and the Lothians," 1839, p. 4.

† Ami Boué, "Essai Géologique Sur l'Écosse," 1820 (?), p. 189.

‡ Sir A. Geikie, "On the Carboniferous Volcanic Rocks of the Firth of Forth Basin," *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. p. 496. "Ancient Volcanoes of Great Britain," 1897, vol. i. p. 452.

§ E. Stecher, "Contact Erscheinungen an Schottischen Olivindiabasen," *Tschermak's Min. Pet. Mittheil.*, 1888, vol. ix. p. 145. "Contact Phenomena of some Scottish Olivine Diabases," *Proc. Roy. Soc. Edin.*, 1888, vol. xv. p. 160.

‖ H. W. Monckton, "The Stirling Dolerite," *Quart. Jour. Geol. Soc.*, 1895, vol. li. p. 480.

¶ E. Stecher, *loc. cit.*, p. 200.

interesting observation that olivine probably occurs in the chilled dges of the quartz diabases, though it is absent from the interior, a fact which we have repeatedly been able to confirm. The augite is usually pale coloured, idiomorphic and very commonly twinned. The felspars are thin plates, tabular on the brachypinacoid. The smaller may show only simple twinning, but the larger have often albite, Carlsbad and pericline lamellæ.

These minerals contain only a few small enclosures of dark glass. At a quarter of an inch from the contact the matrix of the dolerite is finely granular, microcrystalline and possesses neither fluidal nor spherulitic characters. It consists then of minute grains of greenish augite, iron oxides, and small lath-shaped felspars, with usually also very minute irregularly shaped, pleochroic scales of yellow brown biotite. These are very rarely idiomorphic, but from their optical characters and cleavage there can be no doubt as to their nature. Dr. Stecher appears to have been the first to observe them, though he was not certain they were biotite.

The margins of these sills are very often brecciaform, both on a macroscopic and microscopic scale, and contain angular pieces of the adjacent sedimentary rocks with less frequently small detached fragments of the already consolidated chilled edges of the intrusion. They are also occasionally vesicular but never in a marked degree; the best instance of this is probably the Blackburn dolerite and picrite sill. The vesicles are filled with calcite, secondary quartz, chlorite or zeolites.

Dr. Stecher reports that he has found porphyritic crystals of quartz in the edge of the Hound Point dolerite. They are described as being surrounded by a zone of calcite or of quartz which sometimes has the outlines of an idiomorphic quartz crystal. The central part is rounded and has a radiate or spherulitic structure like that of chalcedony. There may be small steam cavities filled partially with calcite and partly with chalcedony, but, so far as I have seen, they are always small corroded quartz xenocrysts, no doubt picked up from the sandstones through which the sill has burst. The calcite margin is due to decomposition of the corrosion border of augite and glass which is so often seen around foreign quartz in basic lavas, and in many cases is replaced by secondary quartz. The radiate structure of the central grain is probably, as Dr. Stecher suggests, due to rapid heating; it is sometimes absent and then the quartz breaks up into a mosaic in polarised light. The external outgrowth of quartz is usually in optical continuity with the corroded centre. In the external zone small needles of hornblende may sometimes be seen penetrating the quartz.

The fine-grained porphyritic margins pass very gradually into the granular non-porphyritic centres of the dolerite sheets.

At a distance of an inch or so from the contact the small phenocrysts become infrequent, but, according to Dr. Stecher, the tendency to the development of porphyritic structure is distinctly visible four inches from the margin of the Salisbury Craig sill (*loc. cit.*, p. 154). The structure becomes ophitic or partly intersertal, though the rock may be distinctly finer grained for several feet. The change seems to be brought about by the disappearance of the phenocrysts

and the increase in size of the elements of the groundmass, to which accordingly the minerals of the central part would correspond. A special characteristic of the fine-grained diabases of the vicinity of the margin of the sills is the abundance of skeleton networks of iron oxide, which from their configuration can only be regarded as (titaniferous) magnetite. This was described and figured by Sir A. Geikie * who noted that it is confined to these situations and to some of the dykes.

In some of the olivine diabase and teschenite sills, in which biotite is a normal constituent, it is greatly increased in quantity towards the margin, while the rock becomes also finer grained and assumes a porphyritic in place of an ophitic structure. Mr. Monckton† appears to have been the first to observe these changes in connection with the Barnton dolerite; he describes the lower of the intrusive masses as a mica porphyrite and notes also its lamprophyric affinities.

The abundance of biotite, and its occasionally porphyritic development, are well seen in the edges of the Inchmickery mass (teschenite). At Lochend the margins of the sill in some cases are full of biotite, but in others contain much dark brown hornblende and have a close resemblance to some of the camptonites, though the hornblende is not so highly idiomorphic as in these lamprophyres. Rocks with camptonitic affinities have been noticed at the edges of some of the teschenite sills, but are too much decomposed to be worth description.

WHITE TRAPS.

Where dolerite sills have traversed carbonaceous shales, oil shales or coals, they are often converted into a peculiar yellow or nearly white rock which is known locally as "white trap." Examples of this are fairly common in the Edinburgh district, and a photograph of one of these sills, a little east of the south end of the Forth Bridge, has been published by a Committee of the British Association ("British Geological Photographs," 1904, 1st series, No. 2101). Sir Archibald Geikie has described these changes in more than one place,‡ and Dr. Stecher § has given the microscopical and chemical characters of the Newhalls sill (Queensferry) a special study.

These white traps consist entirely, as Dr. Stecher has shown, of carbonates of lime, magnesia and iron, with kaolin and muscovite. Quartz is not common except as a secondary product. The nature of the chemical changes is rendered obvious by the following analyses :—

* Sir A. Geikie, "On the Carboniferous Volcanic Rocks of the Firth of Forth," *Trans. Roy. Soc. Edin.*, vol. xxix. p. 497, plate xii.

† H. W. Monckton, "On a Picrite and other Associated Rocks at Barnton," *Quart. Jour. Geol. Soc.*, 1894, vol. l. p. 40.

‡ Sir A. Geikie, *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. p. 499. See also his "Ancient Volcanoes of Great Britain," vol. i. pp. 96, 426, 449, 456; vol. ii. pp. 65, 87, 103, 165, 252; and "Geology of Central and Western Fife," pp. 82, 85, 86; "Geology of Eastern Fife," pp. 164, 195, 207.

§ E. Stecher, *loc. cit.*, p. 190.

	I.	II.
SiO_2	46·06	36·8
TiO_2	2·56	2·6
Al_2O_3	15·94	22·95
Fe_2O_3	2·94	—
FeO	7·44	4·08
MnO	0·31	trace
(CoNi)O	nt. fd.	—
BaO	0·10	—
SrO	nt. fd.	—
CaO	7·04	9·73
MgO	4·14	2·85
K_2O	2·76	1·1
Na_2O	4·95	0·5
Li_2O	? trace	—
H_2O at 105° C.	0·55	—
H_2O above 105° C.	4·22	7·7
P_2O_5	0·84	0·75
FeS_2	0·36	—
CO_2	0·11	11·9
Cl	trace	—
Total	100·32	100·96

I. Teschenite, Mons Hill (shore at Whitehouse Point), Dalmeny, Mid-Lothian (13437) (Anal. Mr. E. G. Radley).

II. White Trap, Newhalls, South Queensferry, Mid-Lothian (Dr. E. Stecher, *loc. cit.*, p. 190).

These analyses refer to the same type of rock originally, as the white trap is presumably an altered sill emanating from the Mons Hill laccolite. If we consider that the alumina has been constant, as the least soluble of the more important components of the teschenite there has been a great loss of alkalies, while a considerable proportion of the iron, magnesia and silica of the original rock has also been carried off in solution. The principal increase is in carbonic acid and water; some of the smaller components, such as titanium and phosphoric acid, have been little affected. Dr. Stecher calculates that in the white trap there are 26·6 per cent. of carbonates of lime, iron and magnesia with 56 per cent. of kaolin. The remainder is muscovite, quartz (possibly some felspar) and titaniferous iron oxides.

Microscopic slides of the Newhalls white trap and of other white traps confirm these inferences from the analyses. The rocks consist of patches of carbonates, with areas of isotropic, nearly colourless and apparently amorphous materials which seem to be mainly kaolin. Grains of dark iron oxide more or less crusted over with yellow leucoxene are the only other constituents of the mass. In the less completely altered portions of the Newhalls sill crystals of plagioclase felspar may still be detected with skeleton growths of iron oxide, such as are frequently seen in the chilled margins of the intrusive dolerites. Other white traps from the Lothians and Fife show the same features. In many of them the carbonates have a yellow colour, especially near their margins, indicating that they contain some iron. Quartz occurs in many, but is not abundant; muscovite and zeolites

are usually absent. Except where there are residues of felspar the iron oxides are the only original minerals which can be identified.

Between crossed nicols these rocks show no well-defined structure, but patches of carbonates, kaolin and iron oxide are indiscriminately scattered through the sections. It is very interesting, however, to observe that in ordinary light the outlines of the original ingredients are clearly traceable. Lath-shaped pseudomorphs after felspar and patches of less regular shape having the outlines of augite and olivine in the fresh rocks may be recognised; the iron oxides also preserve their characteristic shapes. It is possible, in fact, to tell which rocks were porphyritic or ophitic, and the structures of the fine-grained or aphanitic group are equally well shown. We look, so to speak, on the ghosts of the primary minerals, still retaining their form while their substance is entirely changed.

This shows that these rocks consolidated as normal facies of dolerite in spite of the presence of those organic gases which had been driven out of the carbonaceous shales by destructive distillation set up on contact with the liquid, molten intrusion. As the temperature fell, these gases were able to completely destroy the first suite of minerals, and to replace them with others of secondary nature. At high temperatures carbonic acid and organic gases are powerless to attack the rock-forming silicates. This is in accordance with many well-known facts; the magma of a volcano is charged with steam and carbonic acid, but the freshly consolidated rocks show no trace of their action; the same gases rising through similar rocks at ordinary atmospheric temperatures are powerful agents in effecting decomposition by solfataric action. The white traps, then, were produced by the operation of organic gases on solid normal intrusive rocks during cooling and at comparatively low temperatures. Their special feature is the very complete nature of the changes effected. The process must have been a rapid one when once a suitable temperature had been reached by the igneous rock.

CONTACT ALTERATION OF THE SEDIMENTARY ROCKS BY THE INTRUSIVE SILLS.

Since the early years of last century the contact alteration produced by the igneous intrusions (especially that of Salisbury Craigs) has been the subject of repeated comment. Although in most cases the changes are sufficiently obvious to the naked eye they are usually far from striking on microscopic investigation, and no full account of them appeared till Dr. Stecher's paper was published.*

The contact alteration produced by the teschenite-picrite sill of Inchcolm has been fully investigated by Campbell and Stenhouse.†

The purer sandstones are changed into lustrous quartzites consisting of a closely fitting mosaic of small quartz grains, with felspars, white mica, zircon, tourmaline and iron-ores, all of which are probably original. These alterations are well seen at Hound Point, Salisbury Craigs (Plate XI. Fig. 6), Duddingston Loch, Rosyth Castle, and many other localities. At Salisbury Craigs Dr. Stecher detected small

* E. Stecher, "Contacterscheinungen an Schottischen Olivindiabasen," *Tschermak's Min. Pet. Mittheil.*, 1888, vol. ix. p. 145.

† *Loc. cit.*

crystals of pyroxene in the impure sandstones, and regarded them as probably due to permeation by the igneous rock; but they are not uncommon elsewhere, especially when the sandstone was originally somewhat calcareous, and may quite well have been formed by recrystallisation of the interstitial cementing materials. These pyroxenes occur only in small granules, and are pale green or nearly colourless. Brown biotite has been formed in some of the more argillaceous sandstones at Rosyth Castle, Cult Ness, and in some other localities. A fine cryptocrystalline substance, like that described below in the arenaceous shales, appears between the sand grains of some of these rocks.

The purer shales are converted into hornstones, so fine grained as to resemble cherts, and dark green or black in colour, but weathering white, pale green, yellow or buff. They are sometimes banded or irregularly flaked. Naked eye inspection reveals little except scattered, very minute quartz grains or scales of mica in a cryptocrystalline matrix. Under the microscope they present a variety of appearances, but consist essentially of small quartz grains lying in a very fine, slightly granular, cryptocrystalline substance, which has apparently resulted from the more or less complete fusion of the argillaceous portion of the rock. The quartz grains appear from their outlines to have suffered partial corrosion. In the fine matrix small scales of white mica or, less commonly, of brown biotite have been formed. Crystals of zircon and grains of rutile are present also, the zircon probably in its original state, but the rutile obviously recrystallised in short prisms. Changes of the same kind have been described by Mr. Hutchings in shales which have been contact altered by the Whin Sill.* These phenomena are well seen in some of the fine-grained, reddish "porcellanites" at Salisbury Craigs and also at Inchmickery, Barnton and other places.

In a few cases these baked shales show an indistinct spotting due to aggregations of chlorite or of organic matters; they then resemble desmosites and spilosites.†

From the edge of the Hound Point sill a dark altered shale was obtained which showed clear spots, elongated in one direction but hexagonal in cross section (Plate X. Fig. 1). They consist of calcite and other secondary products, but are obviously pseudomorphs after some mineral, and to judge by their forms it is probable that the mineral they replace is cordierite.

The purer limestones are marmorised by the action of the dykes and sills, though only for a distance of an inch or less from the contact. The impure limestones yield fine-grained calc-silicate rocks which may contain pyroxene, wollastonite, garnet, epidote, sphene, vesuvianite, alkali felspars and a variety of other minerals. At Auchinoon, about five miles south-west of Balerno, at the margin of a basic sill there are fine dark green hornstones which have evidently originated by the contact alteration of impure argillaceous limestones. They consist largely of granular yellow-green augite, occasionally showing crystalline outlines; epidote appears also in some of the slides, and there is much chlorite and some green hornblende, which are probably secondary. Large quartz grains are also present and

* Hutchings, W. M., "An Interesting Contact Rock," *Geol. Mag.*, 1895, p. 122.
† R. Campbell and A. G. Stenhouse, *loc. cit.*

often have embayed and corroded borders as if they had been attacked by the surrounding groundmass, while felspar is an important constituent in some of the rocks. It may be polysynthetic or untwinned, and though generally of irregular form may be idiomorphic, and seems likely to be of new formation or at least recrystallised. In some bands the augite occurs as large irregular crystals which are perfectly filled with minute enclosures of quartz, felspars and other minerals. No garnet was identified in the sections. The matrix of these rocks is very fine grained, but in places seems resolvable into an aggregate of quartz and felspar, obscured by chlorite and other secondary products; elsewhere it is too fine grained for microscopic analysis. One band is filled with small hexagonal scales of ilmenite, many of which are so thin that they are transparent and have a dark-brown colour.

The most interesting of the altered calcareous rocks of this sheet is the nodular rock from the edge of the Barnton sill mentioned by Mr. Goodchild * and commented on by Professor Rosenbusch.† It is a thin seam and shows parallel bands of red colour (garnet), green (pyroxene), brownish green (vesuvianite) and round white spots one or two millimetres in diameter (mainly wollastonite) (see Plate X. Fig. 3).

Sections prepared from this junction show that the margin of the intrusive mass is a fine-grained aggregate of idiomorphic olivine and augite, with some interstitial decomposed felspar and dark brown biotite, and a little deep green hornblende. Between the two rocks there lies a thin zone (about ·3 mm. wide), consisting entirely of purplish brown augite, very like that of the picrites and picrite porphyrites, and quite unlike the pyroxene of calc-silicate rocks; it indicates an interfusion of the two masses along their line of contact, though only for an infinitesimal distance. This is followed by a zone (about a millimetre thick), consisting of granular, green and brownish green augite, green or colourless rounded garnets, a little iron oxide, epidote, wollastonite and dark green hornblende. The next zone, about two millimetres wide, consists principally of small isotropic garnets with pale green pyroxene, epidote, some untwinned felspar, dark green hornblende and iron oxides. Outside this there is a banded desmosite or baked shale.

The spotted rock above mentioned (Plate X. Fig. 3) is very largely composed of wollastonite, which forms the round white spherulites visible in the hand specimen, and also, mixed with chlorite and small granules of sphene, composes most of the matrix in which the spherulites lie. There is usually a very turbid, fine-grained central area to each spherulite and an external radiate part with larger transparent fibres. The wollastonite occurs only in needles which are thicker in the outer part of the spherulites than at the centres, where they are mixed with chlorite and other secondary minerals. It is never idiomorphic.

A few doubly refracting garnets of dodecahedral type occur also in this zone. They are spotted with rounded enclosures and have good idiomorphic outlines. The idocrase occurs as long tapering rods forming star-shaped groups embedded in calcite or fibrous wollastonite,

* J. G. Goodchild, "Note on the Minerals Observed in the Railway Cutting near Barnton, Edinburgh," *Trans. Edin. Geol. Soc.*, 1893, vol. vi. p. 301.

† H. Rosenbusch, "Mikroskopische Physiographie," 1896, 3rd ed. vol. ii. p. 1159.

and is of very pale brownish green colour. The transverse sections of the prisms have the typical octagonal form, with four of the faces larger than the other four. Granular sphene, epidote, green fibrous hornblende and chlorite are the other ingredients of this interesting rock.*

The Olivine Basalts and Porphyritic Olivine Dolerites.

The distinctive features of this group are the presence of phenocrysts of olivine, augite and plagioclase felspar, or of one or more of these minerals, in a finely crystalline or partly glassy matrix. They include by far the greater part of the Carboniferous lavas, and also a considerable number of small intrusive masses, which form sheets or necks. Fluxion arrangement is common both in the phenocrysts and in the minerals of the groundmass, and these rocks are frequently vesicular, especially on their upper and lower surfaces. They all contain olivine or pseudomorphs after it. Porphyritic augite is also nearly universal, but many of them show few or no phenocrysts of plagioclase felspar; in the groundmass augite and plagioclase are constantly present with or without small quantities of glassy base. A few of these rocks have been described by Allport and by Dr. Teall. Sir A. Geikie has given a general account of them, based on his own researches and on those of Dr. Hatch and Professor Watts. Their classification, as given in Sir A. Geikie's "Ancient Volcanoes of Great Britain," is adopted here with a few modifications rendered necessary by the extended investigations.

It will be useful to give a synopsis of the classification of the olivine basalts and porphyritic olivine dolerites, showing their main points of difference and the authority who first established the group.

I. Rocks with *conspicuous phenocrysts* in a fine groundmass which may be partly glassy but is *not ophitic.*

A. Lion's Haunch type, with abundant large phenocrysts of olivine, augite and plagioclase felspar (Hatch) (Plate XII. Fig. 1).

B. Dunsapie type, similar to above with coarser groundmass and usually some analcite and biotite (Plate XII. Fig. 2).

C. Craiglockhart type, with large phenocrysts of olivine and augite (but not plagioclase felspar) (Hatch) (Plate XI. Fig. 3, Plate XII. Fig. 3.).

D. Markle type, with numerous large phenocrysts of plagioclase felspar; olivines small and inconspicuous (Hatch) (Plate XII. Fig. 4).

II. Rocks with *small and inconspicuous phenocrysts* in a finely crystalline or partly glassy groundmass, *not ophitic.*

A. Dalmeny type, with many small phenocrysts of olivine, few of augite and felspar (Hatch) (Plate XII. Fig. 5).

B. Hillhouse type, many small porphyritic olivines, few phenocrysts of augite; groundmass full of augite with little felspar, sometimes partly glassy (picrite type of Hatch) (Plate XII. Fig. 6).

C. Analcite basalts, with small phenocrysts of olivine and fewer of augite; patches of analcite in the groundmass.

III. Porphyritic olivine dolerites with *sub-ophitic or micro-ophitic* groundmass.

A. Jedburgh type, with porphyritic olivine and felspar (Watts) (Plate XI. Fig. 4).

* W. M. Hutchings, "Contact Rocks of the Whin Sill," *Geol. Mag.*, 1898, p. 72. J. Allen Thomson, "Inclusions in Volcanic Rocks," *Geol. Mag.*, 1907, p. 490.

B. Kilsyth type, with large porphyritic felspars and smaller phenocrysts of olivine (Watts).

C. Gallaston type, with porphyritic olivine only (Hatch).

Limburgites, containing little or no felspar, groundmass often glassy (Hatch).

Dr. Falconer has classified the lavas of the Bathgate Hills in five groups, of which the first corresponds fairly closely with the Gallaston type; the second and third are the same as Dr. Hatch's Dalmeny type; the fourth is identical with our Hillhouse type, while the fifth is similar to the limburgites.

I. A. *Basalts of the Lion's Haunch Type* (Plate XII. Fig. 1).—The group includes rocks with large and conspicuous phenocrysts of plagioclase felspar, augite and olivine, in a groundmass which is either granular and holocrystalline or contains a small amount of glass. The Lion's Haunch basalt is exceedingly well known; its microscopic characters have been described by Dr. Teall * and Mr. Harker,† and figures of it are published by Dr. Teall ‡ and Professor Cole.§ Its large olivines are only slightly corroded and partly serpentinised. The augite is highly idiomorphic, brownish and sometimes zonal. The zoned, well-formed felspars are bytownite or a basic labradorite near their centres, but at their margins pass into medium labradorite. They show Carlsbad, albite and pericline twinning in great perfection.

Glass enclosures are frequent in the phenocrysts and often show a small immobile bubble, microlites of plagioclase and augite, and branching skeletons of iron oxide. The felspar has often a honeycombed appearance owing to the abundance of these enclosures, which may also be arranged in zones. The groundmass is not fluidal and consists of small, often idiomorphic, plagioclase felspars, granules of pale augite, octahedra of magnetite and a very little pale brown glass.

The basalt of the Haggis Knowe and Long Row, Arthur's Seat, belongs to this group also, but its phenocrysts are fewer, smaller and less perfectly idiomorphic; its groundmass is more felspathic and contains many small agglomerations of granules of augite sometimes with a radiate structure, and occasionally having a central patch of turbid analcite. These "augen" of augite in the groundmass of basalts, as pointed out by Rosenbusch,‖ are well known and of widespread occurrence, though their origin is not altogether clear. They may result from the resorption of foreign grains of quartz.¶ In other parts of the Long Row the groundmass is micro-ophitic. Typical Lion's Haunch basalts are very rare in this sheet, though occurring in many parts of Central Scotland in considerable numbers.

I. B. *Basalts of the Dunsapie Type.*—A very closely allied type, however, represented by the *Dunsapie basalt*, Arthur's Seat, is more common (Plate XII. Fig. 2). In these the groundmass is holocrystalline and nearly panidiomorphic as the augite forms small perfect prisms, the magnetite occurs in sharply defined octahedra and even the felspar has often rectangular outlines. The porphyritic purplish brown augite has continued growing during the formation of the groundmass, and

* J. J. H. Teall, "British Petrography," 1888, p. 188.
† A. Harker, "Petrology for Students," 1902, 3rd ed. p. 204.
‡ J. J. H. Teall, "British Petrography," 1888, plate xxiii. fig. 1.
§ G. A. J. Cole, "Aids in Practical Geology," 1902, 4th ed. p. 259.
‖ H. Rosenbusch, "Mikroskopische Physiographie," 1896, 3rd ed. vol. ii. p. 990.
¶ "Geology of East Fife," *Mem. Geol. Sur.*, 1902, pp. 399, 400.

has an external border enclosing many small felspars. Porphyritic plagioclase and olivine are both abundant, and in this group a small amount of dark brown biotite and turbid analcite are fairly constant accessories. The rocks of St. Leonard's Hill and Heriot Mount are very similar to that of Dunsapie. Both contain a considerable amount of analcite and some biotite, but show less olivine and augite than the Lion's Haunch basalt, and have a more coarsely crystalline groundmass. Fresh specimens from the Dasses and the Windy Gowl have the same composition and structure. The basalt of Samson's Ribs,* which contains a very large amount of plagioclase phenocrysts, belongs also to this group. Allport† notes that it contains analcite, calcite and zeolites probably formed in cavities or secondary after a glassy or felsitic base.

In the other rocks the pseudomorphs after olivine consist of green or brown serpentine. In Samson's Ribs basalt they are usually green iddingsite mixed with fibrous calcite. In the presence of analcite, brown biotite, purple augite and much apatite the basalts of the Dunsapie type resemble the analcite olivine diabases above described. Their analcite is secondary and in advanced stages of decomposition is replaced by calcite. It spreads through the felspar in exactly the same way as has been described in the teschenites.

I. C. *Craiglockhart Type.*—Another well-defined type is the *Craiglockhart* rock described and figured by Sir A. Geikie as an anamesite (Plate XI. Fig. 3).‡ It contains conspicuous phenocrysts of augite and decomposed olivine in a holocrystalline matrix of granular augite, plagioclase felspar, magnetite and ilmenite. The augites are often crowded with small glass enclosures containing crystals of felspar and magnetite. The freshest examples of this group are found in the King's Park south-east of St. Anthony's Chapel (Plate XII. Fig. 3). The olivines of this rock are well preserved; the groundmass consists of small imperfectly formed augites, lath-shaped idiomorphic plagioclase, grains of magnetite and a little analcite, calcite and chlorite. Other specimens were obtained below St. Anthony's Chapel, on the Whinny Hill, 300 yds. north-east of Dunsapie Loch, and in the pathway along the wall in the King's Park, west of Duddingston. Very similar basalts occur near the base of the Calton Hill series, in the Low Calton and on the north side of the Calton Churchyard. In these, however, the augite of the matrix tends to be more abundant and there is a slight approach to ophitic structure.

I. D. The *Markle type* or "labradorite basalts" (Plate XII. Fig. 4) have been described by Dr. Hatch § as containing olivine only in small sporadic grains, while plagioclase felspar is present in numerous large crystals lying in a groundmass of laths, microlites and granules of felspar, together with dispersed magnetite and probably augite, the latter mineral being obscured by a ferruginous product of decay. Having a considerable resemblance to the andesites, owing to their abundant porphyritic plagioclase, these rocks include many of the "porphyrites" of the older writers, but, as shown by Mr. Grant Wilson's

* J. J. H. Teall, "British Petrography," 1888, p. 199.

† S. Allport, *loc. cit.*

‡ Sir A. Geikie, "On the Carboniferous Volcanic Rocks of the Firth of Forth Basin," *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. plate xi. fig. 4.

§ F. H. Hatch, "On the Lower Carboniferous Volcanic Rocks of East Lothian," *Trans. Roy. Soc. Edin.*, 1892, vol. xxxvii. p. 119.

analyses in Dr. Hatch's paper, their real affinities are with the basalts. They form a great part of the volcanic series of the Whinny Hill and St. Margaret's, and of the Calton Hill, Edinburgh.

No fresh example of this type has been found within the area under consideration, and all its representatives are deeply reddened with secondary hæmatite and limonite in the hand specimens, while in the microscopic slides only the felspar preserves its original characters, the ferromagnesian minerals having usually been entirely replaced by iron oxides and calcite. Brown pleochroic iddingsite after olivine is not infrequently seen, but opaque black pseudomorphs of iron oxide (usually hæmatite) are far more common, and as they usually have a platy structure, it is probable that iddingsite was an intermediate, and iron oxide the ultimate product of decomposition. Many specimens have a fluidal matrix, in which lath-shaped felspar is by far the most abundant ingredient. Frequently they have highly vesicular surfaces and some of the rocks are perfect amygdaloids; the steam cavities may be occupied by calcite, hæmatite and chlorite, or may have been emptied by weathering. The cloudy felspars show the three usual types of twinning and are not commonly zonal: their composition in most cases is medium labradorite.

II. A. The basalts of the *Dalmeny type* (Plate XII. Fig. 5), as defined by Dr. Hatch, show abundant rather small olivines, mostly altered into serpentine and calcite, and grains of augite, imbedded in a mesh of slender felspar crystals with microlithic augite and minute granules of magnetite. They are the most abundant and widely distributed of all the types of basalt in this sheet, and occur both as intrusions and as lavas. The type rock comes from a small lava-flow, near Dalmeny Church. Their composition is similar to that of the Craiglockhart type, but the phenocrysts are more numerous and smaller, and in most cases the olivines of the first generation greatly preponderate over the augites. A few small phenocrysts of plagioclase occasionally make their appearance, but they are never numerous. The groundmass shows a certain variety of structure according to the relative abundance of felspar and augite and the presence of minute traces of a glassy base. When any vitreous material is discernible in the slides both felspar and augite are usually in small idiomorphic prisms. The glassy base in such cases is brownish and full of globulites; more commonly the groundmass is holocrystalline and composed of lath-shaped felspars with more or less perfectly formed granules of augite. When the pyroxene forms a considerable proportion of the matrix it shows a tendency to envelop the felspars and produce a micro-ophitic structure; occasionally the groundmass is fluidal. The best-known examples of this type are the basalts at the summit of Arthur's Seat and the Castle Rock, Edinburgh. A few occur also among the lava-flows of the Whinny Hill, Arthur's Seat. In the Bathgate Hills similar rocks occur in great numbers, as remarked by Dr. Hatch and Sir Archibald Geikie,* in fact they form the major part of the volcanic succession. Many of them are much decomposed and vesicular or fluidal, and some contain a small amount of interstitial granular brown glass. The abundance of small olivines in some of these

* Dr. F. H. Hatch, in Sir A. Geikie's "Presidential Address to the Geological Society," *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. p. 131.

rocks is very noticeable. When the groundmass is more coarsely crystalline than usual ophitic structure may appear in parts of it. The following localities may be cited: lowest bed, Kirkton East Quarry;* north-west of Longmuir Plantation; Quarter; Burgh Mill (Linlithgow); 250 yds. west of Hillhouse; Canal Bridge, Railway Station, Linlithgow. Rocks of Dalmeny type are well represented also among the lava-flows in the west cliff of Inchkeith, mostly in an advanced stage of decomposition, and excellent examples come from the cliff west of the blown sand in Pettycur Bay, Fifeshire.

II. B. The *Hillhouse type* (Plate XII. Fig. 6) corresponds to the basalts described as belonging to the picrite type by Professor Watts and defined by Dr. Hatch in the following terms: "Containing large porphyritic olivines, usually more or less serpentinised granular augite, scattered grains of magnetite and only a small amount of felspar, thus approaching picrite."* Professor Watts describes them as follows: "Porphyritic olivine much more common than augite; groundmass of granules of augite set among lath-shaped felspars which are much fewer than in the Dalmeny type."†

This is a small and fairly well-characterised group, the rocks of which seem to be intermediate in position between the Dalmeny basalts and the limburgites. They approach the latter especially in the almost constant presence of a small quantity of clear brown vitreous base filled with skeleton growths of magnetite. Often they are very fresh, and their olivine is usually only partly converted into green serpentine. Augite of a deep reddish brown colour is very abundant, as granules in the groundmass and as small idiomorphic phenocrysts, which show zonal structures (with pale brown centres and darker margins), hour-glass structure and frequent twinning both on the orthopinakoid and on pyramidal faces. They contain also much magnetite in sharply formed octahedra, and their felspar occurs as narrow laths often only simply twinned and frequently having a long glass enclosure in their centres. Their optical characters correspond to basic labradorite and bytownite. Analcite is present in a few slides and seems evidently secondary.

Lavas of this type are very common in the Bathgate Hills, but do not occur in any other parts of this sheet, though they are reported also from Burntisland, Fifeshire, by Dr. Hatch. The following localities may be enumerated: Binns Tower (1 mile south of Blackness); Brachead; 200 yds. north-east of Clarendon; east of Longmuir Plantation; 480 yds. north of Hiltly; Kirkton West Quarry; Hillhouse Quarry; 500 yds. east of Craigmailing.

II. C. *Analcite basalts.* Closely allied to the basalts above described as belonging to the Hillhouse type, are a number of others which contain slightly more felspar in the groundmass, a less amount of glassy base and constantly a small quantity of analcite. As it has been urged that analcite is a primary mineral of some basalts, special attention has been paid to this series, but no evidence has been obtained pointing to a primary origin for this mineral, while

* Sir A. Geikie, *Trans. Roy. Soc. Edin.*, 1880, vol. xxix. plate xi. fig. 5.

† F. H. Hatch, in Sir A. Geikie's "Presidential Address to the Geological Society," *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. p. 129.

‡ W. W. Watts, in Sir A. Geikie's "Ancient Volcanoes of Great Britain," 1897, vol. i. p. 418.

there is clear proof that for the most part it is only secondary. It often fills veins and cavities, at other times it replaces areas of the groundmass, and is not confined to rocks originally holocrystalline, but appears also along with a vitreous groundmass. Whether the rocks in which it is abundant are all intrusive is not quite clear, though this is a point of some interest. Analcite is frequent also in the more weathered rocks of the Dunsapie type (many of which are intrusive). If any nepheline basalts were originally present in this district it is probably among these groups that they have been placed. As typical localities for these analcite-bearing basalts the following may be mentioned: Byres Quarry (east of Bathgate), Hillhouse Quarry (the sill above the limestone), Corsie Hill (Cauldhame).

The occurrences are all restricted to the Bathgate Hills where these rocks seem to be fairly common.

It was shown by Dr. Hatch * that some of the basic igneous rocks of the Scottish Carboniferous system contained many phenocrysts in a finely *ophitic* or partly ophitic groundmass, and Professor Watts † has erected a separate group for these and defined those types.

All of these are represented among the rocks collected from Sheet 32, and as their number is not large, and no striking deviations from the accepted grouping are present, it will be convenient to adopt the existing classification.

III. A. *The Jedburgh Type.*—In the rocks of this class the porphyritic elements are conspicuous, olivine being the principal and felspar of secondary importance. A few slides of the Whinny Hill dolerites (Arthur's Seat) agree very well with Professor Watt's definition and his type slides. The micro-ophitic structure of the groundmass is very perfect (Plate XI. Fig. 4); there are numerous olivines both large and small; and often also there is a very considerable amount of porphyritic idiomorphic plagioclase felspar in small crystals which has sometimes a fluidal arrangement. Among these may be mentioned the central part of the Long Row (specimen taken about the middle of the outcrop); 300 yds. south by east of St. Anthony's Chapel (lava, No. 7 of Whinny Hill series); and the quarry at Scone Gardens, Parson's Green. There is a considerable variation in the size and number of the felspar phenocrysts in this group. Where they are large and numerous there is a transition to the Kilsyth type, where they are small and scanty the rocks are hardly distinguishable from those of the Gallaston group.

III. B. *The Kilsyth type* is strongly porphyritic with large felspar phenocrysts and smaller olivines. It is represented by only one mass within this sheet, that of Buteland Hill, about 3 miles south-west of Balerno.

III. C. In the *Gallaston type* there are many small porphyritic olivines but no phenocrysts of felspar. Among the Bathgate series quite a number of examples of this group have been collected. They include specimens from Broomyknowes, Walton Farm, and a rock from 1800 yds. north-east of Gardener's Hill, and several others. They

* F. H. Hatch, in Sir A. Geikie's "Presidential Address to the Geological Society," *Quart. Jour. Geol. Soc.*, 1892, vol. xlviii. p. 130.

† W. W. Watts, in Sir A. Geikie's "Ancient Volcanoes of Great Britain," 1897, vol. i. p. 418.

are distinguished from the Dalmeny basalts so prevalent in this quarter only by the more coarsely crystalline and more or less ophitic structure of the matrix. Some of them are holocrystalline; others contain a small amount of residual (intersertal) glass filled with skeleton growths of ilmenite, but the augite of the second generation is always later in crystallisation than the felspar and surrounds it or fills up the interstices between it, though never forming large ophitic plates completely enclosing several felspar individuals.

Limburgites are not common in Mid-Lothian and West Lothian, but two rocks are represented in the Survey collection by slides which, though containing a small amount of plagioclase felspar, are so rich in olivine, augite and glassy base that they may fairly be classed with the limburgites. They are from Kipps Hill, Linlithgow, and from a boring near North Hainings, Linlithgow.

MUGEARITES.

Of the rocks which the earlier writers have described as felstones, porphyries and porphyrites, the greater number have proved to be rich in olivine and labradorite and have been assigned, in consequence, to the Markle type of basalts. There are others, however, in which the felspar is more abundant and of more acid character; they contain much olivine but comparatively little augite. These rocks were suspected to be mugearites by the field geologists. These surmises proved correct as the freshest of the rocks of this group are mugearites very closely resembling the type rocks from Skye, described by Mr. Harker.

Mugearites are not numerous or widespread in Mid-Lothian; they occur on the north side of Arthur's Seat, forming the highest lava flows between Dunsapie and St. Margaret's locomotive station. Some of the uppermost beds of the Calton Hill also belong to this group and there are mugearite blocks in the agglomerate of Arthur's Seat. The best examples, however, come from Corston Hill where they occur in the quarry behind Corston.

In the hand specimen these rocks are fine grained, not markedly porphyritic or vesicular. They have a green colour when fresh, not so dark as that of the olivine basalts, but where they are weathered they very often are brown, owing to oxidation of their iron and also to their richness in felspar. Those which have fluxion structure may show a thin platy jointing.

In the microscopic slides (Plate XI. Fig. 5) many of them are much weathered. Their principal components, however, are olivine and plagioclase felspar, with iron oxides. The olivine occurs as numerous small grains, now converted by secondary changes into carbonates, serpentine and limonite. Probably augite was present originally in small quantity, but it, too, is now decomposed and no longer recognizable. Some of these rocks contain small phenocrysts of plagioclase felspar; most of the felspar, however, occurs in elongated narrow prisms which have a parallel arrangement, or fluxion structure that gives the rock its fissility. These lath-shaped felspars, five to ten times as long as they are broad, show rather fine polysynthetic twinning on the albite plan. Carlsbad twinning is not common. Their angles of symmetrical extinction are always low, and their

refractive index nearly the same as that of hard balsam; consequently they belong to oligoclase. Their margins often show narrow bands of untwinned albite felspar with lower index of refraction.

The only other primary constituent of the Corston Hill rock is a deep brown, very pleochroic biotite which forms small scales of irregular shape lying among the felspars. This mica is peculiar in one respect; it is biaxial with an axial angle about 30 degrees and a dispersion so strong that the whole space between the apices of the hyperbolæ have a dark blue tinge. As this biotite seemed to correspond to the description of the problematical brown mineral which Mr. Harker found in the Skye mugearites, the type slides of the latter were examined and proved to contain two distinct brown minerals, one being a variety of biotite identical with that of the Corston Hill rock, while the other belongs to hornblende.*

The analysis (by Dr. Pollard) of the Corston Hill mugearite is given below, along with that of the typical mugearite from Skye.† It will be seen that the rocks have very nearly the same composition except that the Skye mugearite is richer in alkalies, but it should be remembered that the latter is in a state of good preservation, while in the Edinburgh rock the felspars are turbid and somewhat decomposed, and the augite and olivine completely replaced by secondary products.

J. S. F.

	I.	II.
SiO_2	49·29	49·24
TiO_2	2·27	1·84
Al_2O_3	16·66	15·84
Fe_2O_3	7·24	6·09
FeO	4·81	7·18
MnO	0·55	0·29
(CoNi)O	0·04	trace
CaO	5·63	5·26
MgO	2·42	3·02
K_2O	1·86	2·10
Na_2O	4·98	5·21
Li_2O	trace	—
$H_2O-105°$	0·34	1·08
$H_2O+105°$	2·11	1·61
S	nt. fd.	0·03
Cl	? trace	—
P_2O_5	0·24	1·47
BaO	? trace	0·09
CO_2	2·32	—
Total	100·76	100·46*

* Cr_2O_3—tr., SrO—tr., F—0·18 less 0·07 O (=oxygen) for F.

I. Mugearite, Corston Hill, Mid-Lothian (12710).
II. Mugearite, Druim na Criche, Skye (8732).

* Flett J. S., "On the Mugearites," *Summary of Progress of the Geol. Survey* for 1907 (1908), p. 119.

† "The Tertiary Igneous Rocks of Skye," *Mem. Geol. Sur.*, 1904, by A. Harker, p. 263.

CHAPTER XVI.

GLACIAL AND RECENT DEPOSITS.

No systematic re-examination of the glacial and post-glacial deposits was carried out during the recent revision of the Carboniferous areas in Mid and West Lothian, but a brief outline of these stages of the geological record may here be given, based partly on the work of the Geological Survey and partly on the researches of other observers.

The area under description furnishes conclusive evidence that it passed through the various stages of the development and retreat of the ice during the period of maximum glaciation. The great ice-sheet radiating from the Highlands united with that flowing northwards from the Southern Uplands, and a large part of the combined ice-field moved eastwards towards the plain of the North Sea. The Bathgate Hills and the chain of the Pentlands were overridden by Highland ice as shown by the striæ, by the dispersal of stones in the boulder clay, and by the distribution of erratics. The continuity and thickness of the covering of boulder clay in the lowland tracts indicates the intense erosion of the surface of the country traversed by the ice. The phenomena characteristic of the retreat of the ice-sheet are illustrated, in this area, by deposits of sand and gravel, by overflow channels, and by the deflection of water-courses along the flanks of the Pentland Hills. There is no evidence, however, to show that the Pentland Hills nourished independent glaciers during the later glaciation. But the survival of glacial conditions is clearly proved by the occurrence of arctic plants on the floors of silted up lakes in the neighbourhood of Edinburgh and by the remains of the small arctic seal found in the clays of the 100-ft. raised beach at Portobello.

Within the area under description important evidence is furnished by certain buried river channels indicating that, in preglacial time, the land stood higher relatively to the sea than at present. Such evidence forms a natural sequel to the communication made by Dr. Croll to the Edinburgh Geological Society in 1869,* wherein he showed from a series of bores that the ancient course of the river Carron—a tributary of the Forth—lay along a rocky channel traceable from Kilsyth to Grangemouth, the bottom of which was 270 ft. below the present sea-level. This hollow is now filled with various superficial deposits. It followed that evidence might be obtained pointing to the existence of a preglacial channel or valley of the river Forth along the floor of the existing estuary. Confirmation of this inference has been found in the under-sea coal workings at Bridgeness near Bo'ness, where a hollow has been proved to exist

* *Trans. Edin. Geol. Soc.*, vol. i. p. 330. See also H. M. Cadell, "Notice of the Surface Geology of the Estuary of the Forth round Borrowstounness," *Trans. Edin. Geol. Soc.*, vol. iv. p. 2.

which may probably represent this preglacial valley. As already indicated (Chapter IX. p. 135), mining operations have been carried northwards to the margin of this depression. The depth of the estuary at this locality is not more than 21 ft. below Ordnance Datum, and the total thickness of superficial deposits filling the ancient valley must exceed 500 ft. In the mines, the only deposit encountered in the hollow has been boulder clay, but this deposit is known to be overlain by a bed of pliable plastic clay.

The buried river channel of the Almond recently described by H. M. Cadell * supplies confirmatory evidence of the greater elevation of the land in preglacial time. By means of numerous bores in the oil-shale fields the ancient course of the river has been traced approximately from the line of the present river at Mid-Calder, through Clapperton Hall by the west side of Almondell House, through the south-east end of Drumshoreland Wood, to Hiddlefaulds, near Kilpunt. Its trend between these extreme points coincides roughly with that of the present stream. In a bore put down near Clapperton Hall the superficial deposits were found to be 210 ft. thick and their base 100 ft. above sea-level. The site of the bore was about 60 ft. above the river, thus showing that the old channel was 150 ft. deeper than the present stream. At Carlowrie, still farther down the valley, the old channel was found to be 207 ft. below the present river-bank. As the alluvial flat of Carlowrie is only about 90 ft. above sea-level, the bottom of the ancient valley at that locality is 117 ft. below that line. Mr. Cadell is of opinion that the ancient Almond must have flowed northward from Carlowrie between the two prominent ridges of dolerite on either side of Craigiehall, entering the sea close to the site of Dalmeny House, as this is the only part of the coast-line where there is a break in the continuous exposure of rock along high-water mark. From the gradient of the ancient course indicated by the bores he estimates that the bottom of the old bed at high-water mark should be a little over 200 ft. below the surface at Dalmeny. He adds that the former elevation of the land above the present sea-level must have exceeded this amount, as the river gorge did not terminate at Dalmeny, but must have extended northward to its confluence with the main stream. J. H., C. T. C.

Reference may here be made to a portion of the course of the North Tyne, partly preglacial and partly late glacial, preserved in the conspicuous dry valley which is crossed by the North British Railway immediately to the E.N.E. of Borthwick.

Between the foot of Currie Glen and the junction of the North and South Middleton Burns, the latter stream crosses the mouth of a well-defined, deep, trench-like depression which follows the E.N.E. trend of the course of the North Middleton Burn until it is cut off by the railway embankment. The valley is continued on the farther side of the bank for half a mile in a northerly direction to the point where it joins the present valley of the Tyne Water 350 yds. south of Crichton Castle. The upper part of the valley is dry; the lower, north of the railway, is drained by an artificial cut which receives the spring water that flows off the drift slopes on either side.

* *Trans. Edin. Geol. Soc.*, vol. viii. p. 194.

The highest point of the floor of this valley is found about 100 yds. east of the junction of the Middleton Burns, and there is a fall of five feet from this point to the bank of the adjacent stream, which has cut down through the earlier cone of alluvium laid down at the mouth of the Currie Glen. The fall of the valley northwards to the embankment is 30 ft., and from the farther side of the embankment to the Tyne Water 60 ft., making a total fall of 90 ft. in 1500 yds. equivalent to a gradient of 1 in 50. The depth of the gully—measured from the surface of the railway where it crosses the valley—is 130 ft. at the embankment, and from thence to the Tyne Water varies from 140 to 160 ft. The valley has been excavated partly through rock and partly through the superincumbent gravel and boulder clay. Its western side is defined, for some distance north of the railway, by a line of sandstone crags, but farther north it has been eroded entirely in the deep drift deposits. The present carrying capacity of the channel of the North Tyne below the foot of this dry valley is small and quite out of proportion to the width of the valley of erosion.

From a consideration of the facts described above, it is evident that the Borthwick dry valley represents the former course of the combined waters of the North and South Middleton Burns at the time when these streams formed the natural head waters of the North Tyne. They have been subsequently captured by the cutting back of the Gore Water and diverted westwards into the basin of the South Esk. The amount of drainage area thus transferred from the basin of the North Tyne to that of the Esk covers more than ten square miles. C. B. C., L. W. H.

I. GLACIAL DEPOSITS.

The materials throwing light on the history of the glacial period in the area under description may be arranged under the following heads:—

5. Ancient lakes.
4. Sands and gravels.
3. Erratic blocks.
2. Boulder clay.
1. Striated rock surfaces.

Striated Rock-Surfaces.—In the western portion of the area, partly along the western margin of Sheet 32 and partly along the east border of Sheet 31, various striæ have been recorded, many of them in dolerite quarries where the surfaces have been recently laid bare. Thus in the tract between Bo'ness and Linlithgow the direction of the ice-movement varies from east to east 16° south; farther south between Linlithgow and Bathgate the striæ run from east to E.N.E., and in some instances south of east. An example of the last is to be found at Petershill limestone quarry where the trend is E.S.E., as recorded by Mr. Ralph Richardson* many years ago. On the Corston Hill south of Mid-Calder the ice-sheet moved in a north-easterly direction, as indicated by the groovings, while only a few miles to

* "Notice on Glaciated Rock Surfaces (displaying corals) near Bathgate, Recently Quarried Away," *Trans. Edin. Geol. Soc.*, vol. iii. p. 18.

the E.N.E. on the east side of Dalmahoy Hill the trend is a few degrees north of east.

Passing now to the central portion of the area we find that on the dolerite of Dundas Castle and of Corstorphine Hill, on the Castle Rock, on Calton Hill and on the Whinny Hill the ice-markings run a few degrees to the north of east. Farther south, on the southern slope of Arthur's Seat, on Blackford and Braid Hills, at Craigmillar and as far south as Hunter's Tryst, the direction of movement is a few degrees south of east.

Of these ice-worn surfaces in the central area perhaps the most interesting is that on the southern declivity of Blackford Hill, which has become one of the classic spots connected with the early history of Glacial Geology in Scotland. In 1840 it was shown by Charles Maclaren to Agassiz, who at once recognised in the moulded and grooved surface the work of land ice.* Here the cliff of andesite has been under cut and has been worn into a cave which is grooved and striated like the overhanging cliff. The converging striæ at the western entrance of the cave and the diverging markings at the exit plainly show that the ice must have behaved like a plastic substance under enormous pressure due to the thickness of the *mer de glace*. Another striated surface worthy of special mention occurs on the northern face of the Castle Rock, where the ice-markings are horizontal on a vertical cliff of basalt.

Within the Pentland Hills few striæ have been recorded, but those that have been noted are instructive. On the crest of Allermuir Hill, at a height of 1617 ft., ice-markings pointing a few degrees north of east were detected by Dr. Croll and Mr. James Bennie, thus showing that the northern part of the chain was overridden by the ice. Farther to the south-west, in a pass across the Pentlands between the West Kip and Gap Law, about one and a half miles to the north-west of Eight Mile Burn, striæ indicating a south-easterly flow of the ice have been recorded.

It is noteworthy that on the projecting ridges of the Warklaw and Torduff Hills on the north-west slope of the Pentland Hills the striæ indicate a movement of the ice towards the north-east in harmony with the evidence already referred to as occurring on Corston Hill. If these markings were produced during the maximum glaciation, they must indicate an undertow, as boulders from the Highlands are plentiful in the boulder clay in the Pentlands as far to the south-west as the heads of the Esk and Lyne Valleys. But it seems more probable that they were engraved on the rocks when the Highland ice could no longer overtop the hills, but was compelled to flow parallel with the ridge.

East of the Pentland Hills the only recorded striæ occur not far from Walstone, about a mile west of Eight Mile Burn, where they run in a north-easterly direction. These markings may have been produced by ice advancing from the Southern Uplands when the chain of the Pentlands separated the northern from the southern ice. This explanation receives some support from the phenomena presented by the fluvio-glacial gravels of the Mid-Lothian basin, to be referred to in the sequel.

But in addition to the striæ and the flutings engraved on the

* The "Glacial Theory—No. 2." Article published in *The Scotsman*, 2nd January 1841.

rocks, the peculiar contour of the hills called "Crag and Tail," referred to by Sir A. Geikie in the previous edition of this memoir, points unquestionably to the action of land ice. "Many of the more prominent hills consist of a narrow ridge sloping gently towards the east and rising abruptly from the lower ground on the west side. They also commonly have a valley or depression immediately below the steep side. The prominent part consists of hard trap rock, and the tailing declivity of sandstones and shales. 'Crag and Tail' is well displayed by the Castle Rock, by Arthur's Seat and Calton Hill. But perhaps the most striking example in the whole of the district is that of Binny Craig. The summit is 718 ft. above the sea, and 120 ft. above the hollow on the west side, from which it rises precipitously into the most conspicuous hill between Edinburgh and Stirling." *

B. N. P., J. H.

Boulder Clay.—Within the area described in this memoir this deposit forms the chief product of the glaciation of the region, and varies in character according to the nature of the underlying rocks. Thus in the western district it consists of a stiff blue or grey stony clay derived chiefly from the clays, marls and shales of the Lower Carboniferous strata, charged with boulders of the harder sandstones and especially of the associated igneous rocks, together with blocks of volcanic rocks from the Campsie Fells and of the Lower Old Red conglomerates from the Highland border. But perhaps the most conspicuous foreign boulders in this district are those composed of schistose grit, epidiorite, and garnetiferous mica-schist from within the Highland region. In the Pentland Hills the boulder clay is of a reddish tint and of looser texture owing to the great admixture of materials derived from the red sandstones, conglomerates and volcanic rocks of Lower Old Red Sandstone age. These are associated with blocks of various metamorphic rocks from the Highlands. East of the chain it resumes its dark blue colour and tough texture, where it again overlies Carboniferous strata. In the extreme south-east district the character of this deposit changes owing to the presence of a considerable number of greywackes and shales from the Silurian rocks of the Southern Uplands.

A glance at the map will show the wide distribution of the boulder clay over the low grounds, where it forms a nearly continuous covering with the more resistant crags and ridges of igneous rock rising above it. Even in the Pentland Hills only a comparatively small area is free from it. On the top of Allermuir Hill (1617 ft.) Dr. Croll observed a patch of till containing, in association with local stones, fragments of schist and other foreign rocks, showing that the chain must have been overridden by land ice. In the Mid-Lothian basin it swathes the Carboniferous strata even beneath the fluvio-glacial gravels and the raised beaches, the palæozoic rocks being laid bare only in river gorges, on the seashores, on the Roman Camp Hill and in quarries. As an instance of the great depth of this deposit it may be mentioned that in the Breich Water and in the tract to the north it reaches a thickness of 100 ft.

On Cliftonhall estate, near the River Almond, a tusk of the mammoth (*Elephas primigenius*) was found in 1820 during the excavation of the line of the Union Canal between Edinburgh and

* "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, 1861, p. 127.

Falkirk. It measured 39 inches in length and weighed 25¾ lbs. avoirdupois. From the description given by R. Bald the tusk seems to have been embedded in stiff boulder clay.*

One of the best-known sections in the Lothians is that at Hailes Quarry about two miles south-west of Edinburgh, which is of special interest on account of the intercalation of a bed of peat in the superficial deposits. The section was visited by Professor James Geikie in 1878 and described in detail by him in his volume on "Prehistoric Europe," 1881, p. 256. As seen in that year a deposit of tough, blue boulder clay lay at the base, overlain by an irregular bed of sand with some boulders followed by a layer of peat from 1 to 18 in. in thickness. Above the peat, which was lenticular, came pale blue sandy clay often charged with vegetable débris and coarse sandy clay with many angular and subangular stones and boulders, which was covered by a mass of boulder clay from a few feet to several yards in thickness. Professor Geikie regarded the deposits lying between the upper and lower boulder clays as of interglacial age. The plant remains obtained by Mr. Bennie † from the peat were submitted to Mr. Clement Reid ‡ for determination, who came to the conclusion that there are two plant-bearing beds, the lower one resting immediately on the boulder clay and yielding arctic plants in hollows between the boulders, and the newer one containing temperate species in association with various plants usually considered to be only present in this country as weeds of cultivation. The lists determined by Mr. Reid are given in the Palæontological Appendix to this memoir (p. 406).

At Redhall Quarry, near Edinburgh, Mr. John Henderson § noted the occurrence of a bed of peat in association with deposits of sand and gravel which lay between two masses of boulder clay. The fruits and seeds of a large number of plants obtained by Mr. Bennie from this peaty layer have been named by Mr. Clement Reid. From the many weeds of cultivation, capsules of flax, and pieces of charcoal which it contains, he infers that it can scarcely belong to any earlier period than the neolithic ‖ (see Palæontological Appendix (p. 407). B. N. P., C. T. C., J. S. G. W., J. H.

Erratic Blocks.—The evidence obtained from the distribution of boulders derived from sources beyond the limits of the region now under description confirms in a remarkable manner the conclusion already reached from a consideration of the striæ. Though these are now found on the surface, some of them may be relics of the boulder clay. Prominent among the erratics are representatives of the metamorphic rocks of the Highlands, comprising the schistose grits of Leny, Craignahoolie, and Ben Ledi, the Green Beds and schistose epidiorites. These are found on both sides of the Firth of Forth, and they occur sparsely in the Pentland Hills as far south as the Lyne Water. Special reference may be made to the boulder of mica-slate weighing about eight or ten tons on the south-east side of Hare Hill, near Bavelaw Castle, which was first noticed by

* *Mem. Wernerian Nat. Hist. Soc.*, 1822, vol. iv. p. 58.
† *Ann. Scot. Nat. Hist.*, 1894, pp. 46–52.
‡ "Origin of the British Flora," p. 72.
§ *Trans. Edin. Geol. Soc.*, vol. ii. p. 391.
‖ "Origin of the British Flora," p. 86.

Maclaren.* It occurs at a height of 1060 feet above the sea. Erratics of Highland metamorphic rocks are also to be found in considerable numbers in the neighbourhood of Middleton in the extreme south-east corner of Sheet 32, where they have been used in building dry stone dykes. Boulders of granite and diorite like the rocks from the Garabal igneous area appear along the south shore of the Firth between Granton and Leith, and blocks of the same materials have been found in the boulder clay cuttings of the new docks at Leith. Further evidence of the transport of materials from the Highland border is supplied by the occasional occurrence of erratics of Lower Old Red conglomerate with quartzite pebbles, resembling the basal beds of that formation in the Callander and Aberfoyle region. An excellent example of this type has been preserved in West Princes Street Gardens, Edinburgh, at the base of the Castle Rock.

An important link in this chain of evidence has recently been furnished by A. MacEwen Peach,† who has traced boulders of essexite from their source at Lennoxtown, at the base of the Campsie Fells, eastwards to the Firth of Forth. They occur along the south shore of the Firth from Bo'ness to beyond Queensferry till the southern limit of the track is reached between Hound Point and Cramond. On the northern shore they have been found at Rosyth Church and they have been followed eastwards to beyond North Queensferry, their northern limit being a point between Burntisland and Kinghorn. At Hound Point north of Dalmeny, 35 miles from the source of these boulders, the track is 4 miles across.

Amongst erratics the most remarkable instance within the area under description is the transported mass of igneous rock at Comiston sand-pit, in the southern suburbs of Edinburgh, recently described by A. C. Campbell and E. M. Anderson of the Geological Survey.‡ The workings in the sand-pit disclosed three years ago a sheet or mass of volcanic rock, measuring in thickness from 4 to 9 ft. and in length from 135 to 150 ft., and resting horizontally on stratified sand and gravel (Plate VIII.), with little disturbance of the bedding planes of the superficial deposits. At one point the western part of the transported mass rests on a thin layer of stiff clay with occasional stones, which has been traced along the south side of the pit where the volcanic mass is absent. It has been suggested that this huge erratic, which consists of altered lava, may have come from Torduff Hill about two miles to the south-west where a similar rock occurs in place.

The authors suggest that the sands beneath the transported mass were laid down in a lake ponded by the ice-sheet which filled the central valley of Scotland at a period of its retreat when it extended a little to the south of the present site of Edinburgh. They discuss two theories of transport of this sheet of volcanic rock (1) by land ice and (2) by ice floating in this temporary lake, without committing themselves to either hypothesis. But in view of the great size of rock masses which are believed to have been transported by land

* "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Sur.*, p. 126.
† *Geol. Mag.*, 1909, p. 26.
‡ *Trans. Edin. Geol. Soc.*, vol. ix. pt. iii. p. 219.

Transported Mass of Lava resting on Glacial Sands and Gravels, Comiston Sand Pit, near Edinburgh.

ice in Scotland and England, the former theory seems the more probable. B. N. P., J. H.

Sands and Gravels.—These deposits are chiefly met with in the Mid-Lothian basin where they cover considerable areas. Between the Pentland Hills and Bathgate and Bo'ness they form isolated patches of no great dimensions. At these various localities they may have been formed partly by melt water from the retreating ice-sheet and partly in marginal lakes impounded by the ice front.

A wide sheet of sand and gravel covers most of the lower ground that extends northwards from the base of the Moorfoot Hills into the southern part of the area. The gravel seems everywhere to be underlain by boulder clay which is exposed by denudation in the valleys and stream sections. The plateau-like character of the gravelly deposit is well marked between Gorebridge and Borthwick, where the flat summits of the undulating plain rise to a uniform height of between 700 and 800 ft. The gravels are largely composed of greywacke pebbles derived from the Silurian rocks of the adjacent uplands, from which it seems probable that they were laid down when the southern ice had retreated from that area and the drainage was obstructed by the northern ice front.

In the western district between Penicuik and Temple the gravels are more irregularly disposed and often form isolated mounds and kamiform ridges. An examination of this gravel points to its having been derived from the west. A large proportion of the pebbles is composed of volcanic and intrusive igneous rocks similar to those of the Pentland Hills and the country to the west of that range.

About 150 yds. north of Eskbank railway station a section exposes coarse gravel resting upon 8 or 9 ft. of fine sand and clay free from stones and often finely laminated. Similar clay and sand are seen in the cutting half a mile south of the station, where they are overlain by reddish brown boulder clay. A similar sequence is met with in the old clay-pits of Newton Grange, three quarters of a mile S.S.E. of this cutting. These pits are situated a little under the 250-ft. contour line and about the same level as the Eskbank exposure. It seems probable that the sand and stoneless clays at these localities were at one time continuous before the valley of the South Esk was excavated.

Excellent examples of eskers occur on the north-west side of Dalkeith. The largest extends in a general northerly direction for about a mile from Sheriffhall. Another lies about half-way between Drum and Campend, running in a W.N.W. direction for about a quarter of a mile.

Within the Mid-Lothian basin, and on the slopes of the Pentland Hills, instances of dry valleys, belonging to a drainage system initiated at a time when the Highland ice was retreating northwards, are to be found. At least three valleys which run almost parallel with the contour lines, and which are now either dry or occupied by insignificant streams, occur between Rosewell and Redside, one of them extending more than three miles. In various places they are bordered on either side by glacial gravel, and appear to have been cut out of it. They were probably formed at a period when drainage

to the north, directly across the contour lines, was impossible owing to the presence of a barrier of ice.

Between Lawfield and Crossgatehall, on the east side of the Mid-Lothian Coal-Field, we find a number of slight surface features which run nearly parallel to the contours in a general north-east direction. One of these passes near Langlaw and Fuffet, and develops at its northern end into a valley which cuts deeply across some rising ground, which probably at one time formed part of the watershed between the Esk and the Tyne.

On the north-west slope of the Pentland Hills the Bavelaw Burn, instead of flowing directly northward towards the Water of Leith, runs in a north-east direction for several miles, that is parallel to the long axis of the chain—a deflection that is probably due to the cause referred to. In like manner the Walston Burn—a tributary of the Eight Mile Burn on the south-east slope of the Pentland Hills, runs for some distance parallel with the contour lines. It is flanked by a ridge of gravel on the south-east side, and this part of its course may probably represent a marginal channel.

Certain gaps in the ridge of elevated ground extending along the Pentland chain to Blackford Hill may represent overflow channels during the retreat of the northern ice, as for instance the hollow between Bells Hill and Black Hill, the depression running east by Mortonhall, and the gap between the Braid and Blackford Hills.

In the western portion of the area (Sheet 31), during the retreat of the great ice-sheet, a marginal lake seems to have been formed between the ice front on the west and the ridge of the Bathgate Hills trending north and south, the overflow from which was gentle and produced no lasting feature. In the earlier stages of retreat it was accomplished round the southern end of the hills at the 500-ft. level, and the gravels and sands of Bathgate testify to the amount of detritus discharged into the lake by diverted streams and by the waters of the melting glacier. These gravels, etc., only extend for a short distance into one-inch Sheet 32. They form several elongated mounds at Dechmont.

Near Linlithgow a series of sands and gravels occurs below the 230-ft. level, and is well seen on the banks of the Avon, where it forms the Avontoun ridge. Eastwards, it passes into a conspicuous series of mounds of sand in the hollow in which the town stands. Near Springfield and Grougfoot, glacial sands and gravels are also widely developed, often arranged in mounds with their long axes running nearly east and west, and in one place reaching a height of 300 ft. above the sea.

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Ancient Lakes.—Within the city of Edinburgh and in its neighbourhood, various patches of alluvium mark the sites of former lakes and tarns, which were due to the irregular distribution of the boulder clay. These deposits are of special interest as they throw light on the climatic conditions that prevailed after the disappearance of the ice from the lowland districts. The late Mr. James Bennie of the Geological Survey was the first to discover in these old alluvia the remains of arctic plants, which clearly prove that they date back to glacial time. Much of the detailed information which we

possess regarding these deposits is mainly based on observations made by him during the close of his career. In 1889 he contributed, conjointly with T. Scott, a paper on "The Ancient Lakes of Edinburgh" to the Royal Physical Society, among which he enumerated (1) the North Loch, extending along the North British Railway from the Castle Rock to a point beyond the North Bridge; (2) Bristo Port Lake; (3) the loch on the north side of Blackford Hill; (4) Jordanvale Lake; (5) the Borough Loch, now the Meadows; (6) Holyrood Lake; (7) Corstorphine Lake. The various deposits are described by Mr. Bennie, and lists of the mollusca and ostracoda, determined by Mr. Scott, are given, together with tables showing their distribution.*

Of these vanished lakes, the one at Corstorphine is by far the largest, as its alluvium extends from Coltbridge westwards to near Gogar Park—a distance of about four miles (see Sheet 32). Fortunately the deposits of this lake were carefully studied by Mr. Bennie during the construction of a trench in connection with the Water of Leith Purification Scheme (1890–93). The cutting was about 3 miles in length, about 20 ft. in depth and 5 ft. in width. The following table, abbreviated from his descriptions,† gives in descending order the sequence of deposits there displayed :—

6. An upper bed of sand and gravel, 6 or 7 ft. in thickness, often laminated and sometimes false-bedded, but with hardly any organic remains.
5. The lake marl, consisting of calcareous mud, crowded with the ordinary lake shells, and felted with long ribbon-like stems of water plants. It varied in thickness from 2 to about 20 ft.
4. The arctic plant bed composed sometimes of pure drift with no clay or mud, but most frequently of fine clay, mud or silt, with the leaves in thin layers. In other places the leaves were scattered singly through the deposits, sometimes with much débris, consisting of vegetable fibres, dried rootlets, or epidermis of water plants, sometimes with quantities of twigs about an inch long, stripped of bark, rounded at the ends and water-worn. Fruits of the arctic willow were of frequent occurrence.
3. Fine laminated clay, evidently representing the finer silt washed out of the boulder clay on the adjacent ground, free from peat and marl, and with no organic remains except the rootlets of water plants.
2. Coarse grey sand with occasional stones, probably the residue of the boulder clay from which the finer silt had been washed away.
1. Boulder clay of unknown thickness, but irregular as it sometimes reached the surface and sometimes lay beneath the sewer cutting.

The seeds and leaves obtained by Mr. Bennie from this old alluvium were determined by Mr. Clement Reid (see Appendix, p. 408), who states that the vegetation consists mainly of dwarf willow and birch, with a few herbaceous plants of species still living within the Arctic Circle.‡ The arctic species no longer living in the lowlands of Scotland comprise willows (*Salix polaris, S. herbacea, S. reticulata*), the dwarf birch (*Betula nana*), the white dryas (*Dryas octopetala*) and *Oxyria digyna*. Of these forms *Salix polaris* is the only one now extinct in Britain. Mr. Reid regards the deposit as late glacial and contemporaneous with the plant beds at Hailes in

* *Proc. Roy. Phys. Soc. Edin.*, 1888–90, vol. x. p. 126, and H. M. Cadell, "A Map of the Ancient Lakes of Edinburgh," *Trans. Edin. Geol. Soc.*, 1888–93, vol. vi. p. 287.

† *Ann. Scot. Nat. Hist.*, 1894, vol. iii. p. 46.

‡ *Brit. Assoc. Rep.*, 1892, p. 716.

Mid-Lothian and Dronachy in Fife.* Confirmatory evidence of the arctic conditions under which the peaty layer accumulated in Corstorphine Lake is furnished by the occurrence in it of abundant remains of *Lepidurus glacialis* [*Apus*], a phyllopod now found living only in the freshwater lakes of Greenland and Spitzbergen.

Regarding the arctic plant bed in Hailes Quarry, Mr. Bennie records that it was found at the bottom of a series of deposits, which proved the existence of a tarn or lochan in a hollow space between boulder clay hillocks in the north-east corner of that quarry. His interpretation of the descending sequence of materials is given in the subjoined table:—

7. Vegetable soil, about 2 ft. thick.
6. Ochreous sand with no organic remains, about 6 ft. thick.
5. Coarse sands, gravels and silts from 8 to 10 ft. in thickness, charged with hazel nuts, acorns, alder seed cones and stones of fruits, with much drift-wood in the shape of twigs, pieces of bark of trees and in rare cases tree trunks 8 or 10 in. in diameter.
4. Silts with seeds of *Potamogeton* and occasional patches of solid peat with seeds of *Potamogeton*, *Menyanthes* and *Carices*. In addition to these forms circular bodies supposed to be statoblasts of a freshwater polyzoon and the remains of *Daphnia* were found.
3. The arctic plant bed consisting of fine sandy mud or silt from 1 to 2 ft. thick, in which the relics of vegetation occurred generally as thin layers and sometimes scattered through the deposit as single leaves. As in the peaty layer in the Corstorphine Lake the plants were here associated with abundant remains of the phyllopod *Lepidurus glacialis* [*Apus*].
2. A layer of large stones evidently washed out of the boulder clay.
1. Boulder clay representing a true ground moraine.

Passing from these interesting relics of the vegetation of the Edinburgh district in late glacial time, we may here allude to an important discovery made by the late Mr. Macfie of Dreghorn, which gives a glimpse of the mammals that frequented the region after the retirement of the ice-sheet. In a rock fissure in the basic andesite at Green Craig in the Pentland Hills, about three-quarters of a mile south of Dreghorn Castle, he found an ossiferous breccia which yielded bones representing several animals. These were described by Mr. James Simpson of the Anatomical Department, University of Edinburgh, who states "that the condition of the bones, as well as their environment, points unmistakably to the fact that they constitute part of the contents of the lair of some carnivorous animal, for they are gnawed and split up in the manner so characteristic of the bones of the prey of such carnivores as the hyæna. Into this lair or den the animal must have dragged portions of its victims, consisting chiefly of limbs, to be subsequently devoured." †

He determined portions of the skeletons of five individuals of the Cervine group of deer, two right radii of two horses, a radius and ulna of the wolf, and teeth and portions of the lower jaw of the fox. The presence of reindeer was proved by the identification of parts of the skull and of the metacarpal and metatarsal bones.

From the absence of boulder clay and of ice-worn and striated stones in the fissure, Mr. Henderson inferred that the ossiferous breccia was formed after the general glaciation of the region. The fissure was mostly filled with weathered and angular fragments of the

* "Origin of the British Flora," p. 62.

† *Trans. Edin. Geol. Soc.*, 1886, vol. v. p. 294.

andesite of the Craig, the bones occurring in a layer about 3 ft. in depth near the bottom.*

In this connection it is interesting to observe that the remains of the red deer, the horse, the ox, the goat and the field vole were found by the workmen in the superficial deposits in Hailes Quarry, which were described by J. Simpson and Dr. Hepburn in 1899.† At a later date, human remains were discovered in association with those of the red deer and the ox in the same quarry. J. H.

II. RAISED BEACHES.

In the area now under description, terraces representing raised beaches or their inland extension as river terraces occur at the following approximate levels above Ordnance Datum: 125–130, 100, 75, 50, 25–30 ft. respectively.

To the east of Edinburgh, between Wallyford and Smeaton, the landward margins of the highest platform can be traced for more than a mile. South of Smeaton, the 125-ft. beach appears to rise gently in a southerly direction till it reaches 150 ft. at Cowdenfoot. The southern limit is very indefinite. The gravel that forms the uppermost layer under a great part of Dalkeith slopes gently to N.N.E., and perhaps represents a fluviatile deposit that was formed contemporaneously with this beach. At Duddingston and to the north-east of Craigmillar Castle, large alluvial flats occur a little above the level of the 130-ft. platform and may be synchronous with it.

The brick clay exposed at the Portobello clay-pits, which has been proved by boring operations to be 100 ft. thick, is classed by Dr. James Geikie with the 100–125-ft. raised beach deposits, and, as already stated, has yielded the remains of the small arctic seal.‡ At Errol, beds which are supposed by him to be of the same age have yielded shells of an extremely arctic type, such as *Pecten grœnlandicus, Leda arctica, Tellina myopsis.*§ The inland margin of this beach can be traced round the east end of the Calton Hill and westwards through the city by Gayfield Square and Great King Street. West of Edinburgh the inner edge of the highest terrace clings closely to the 100-ft. contour line, but it is not persistent. The platform is cut out of boulder clay, and, at Blackness, it yields a brick clay of good quality, formerly used for the manufacture of bricks and tiles. To the south of Dalmeny House this terrace reaches a little beyond the Edinburgh and Queensferry road, and farther south it has been traced up both sides of the valley of the

* *Op. cit.* p. 302.

† J. Simpson and D. Hepburn, "On Mammalian Bones found during Excavations at Hailes Quarry, near Edinburgh," *Trans. Edin. Geol. Soc.*, vol. viii. p. 27; and D. Hepburn, "On the Association of Human Remains with those of the Red Deer and the Ox in Hailes Quarry," *op. cit.* vol. viii. p. 197.

‡ "The Great Ice Age," 1894, 3rd ed. pp. 272, 273, and Dr. Allman, *Edin. New. Phil. Journ.*, 1859, vol. x. p. 131.

§ "The Great Ice Age," 1894, 3rd ed. p. 275, and Dr. Jamieson, "On the History of the Last Geological Changes in Scotland," *Q.J.G.S.*, 1865, vol. xxi. pp. 196–199. It should be stated, however, that the latter author does not admit the existence of any 100-ft. raised beach on the east side of Scotland ("On the Raised Beaches of the Geological Survey of Scotland," *Geol. Mag.*, 1906, No. 499, p. 22).

Almond to Kirkliston. During this period a large landlocked estuary existed between Hallyards and Craigiehall, and was connected by a narrow neck with the outer channel at Cramond Bridge. Numerous bores over this area show that the 100-ft. beach deposits vary in thickness from 9 to 43 ft., and consist of running sand, mud and gravel resting on boulder clay.

Still farther west, a raised beach, which reaches a height of 125 ft., is well seen in Bo'ness, and beyond that town near Kinneil House, thence it can be followed with occasional gaps to Inveravon, and up the Avon as far as Linlithgow Bridge. Near Bo'ness a slightly lower terrace about the 100-ft. level is observable.

The 75- and 50-ft. terraces are to be found only in the area lying to the east of Granton in Sheet 32.

The lowest of these beaches, from 25 to 30 ft., forms a striking feature along the coast between Preston Grange and Bo'ness. The brick clays, which, at Portobello, were found by Hugh Miller to contain *Scrobicularia piperata*, probably belong to this beach. Near Fillyside, Leith, as recorded by Hugh Miller, the boulder clay along the high-water line is perforated by *Mya truncata*, with the siphuncular end uppermost, and other shells in their natural position. These observations show that at a former period what at present forms the high-water line must have lain within the habitat of the *Mya*, that is, between 18 and 40 ft. lower than at present.*

West from Leith the 25-ft. beach forms a narrow shelf bounded inland by a high bluff, upon which the lower parts of Newhaven and Granton are built. Here the common shells of the present shore have been found in these deposits. From the mouth of the river Almond to Blackness Castle the inner edge of this terrace appears to reach a height of from 35 to 40 ft. above sea-level. On exposed headlands, such as Snab Hound Point and Whitehouse Point, this beach is represented merely by a rock notch, westwards towards Bo'ness it is a terrace of deposition.

III. ALLUVIAL TERRACES.

In Dalkeith Park the higher raised beaches, and other older deposits, have been carved into a series of river terraces—at least six in number—which are unusually distinct. The topmost terrace is only about 20 ft. below the level of the highest raised beach.

To the east of Kirkliston the river Almond meanders through a series of large flat meadows, which are coloured as alluvium on the one-inch map, but in reality compose the platform of the 100-ft. beach overlain by a thin covering of freshwater deposits.

The river Almond from Kirkliston to Blackburn traverses a deep narrow valley, to a large extent cut out of boulder clay, with narrow alluvial terraces along the bottom. At Livingston Mill a good section shows the highest river terrace resting on an irregular denuded surface of boulder clay.

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* "Geology of the Neighbourhood of Edinburgh," *Mem. Geol. Surv.*, p. 129; also Hugh Miller, "Edinburgh and its Neighbourhood," 1870, p. 110.

CHAPTER XVII.

ECONOMICS.

Coal and Ironstone.

Mid-Lothian Coal-Field.—In the preceding chapters the geological structure and lithological characters of the strata in different areas have been described, but future mining exploration will doubtless add much to our knowledge of certain parts of the field. Recent statistics show that the development of the Mid-Lothian coal-field has been making steady progress. In the year 1903 the output of coal in this county amounted to 1,623,390 tons, but in 1905 it had increased to 1,914,015 tons.* None of the Edge Coals has yet been mined right across the basin, and the "winning" of under-sea coal is just beginning. Mr. J. S. Dixon† estimates that the quantity of coal, in seams one foot or more in thickness, still available in the Lothian coal-field—under which term are included the Haddingtonshire coal basin and parts of Peeblesshire as well as the Mid-Lothian Coal Basin—amounts to 2,520,311,573 tons. To this quantity is added one-third of the supply which is estimated to occur beneath the Firth of Forth,‡ this being the proportion expected to be mined by collieries on the Lothian shores. It is inferred that the coal resources of the whole area could maintain the present output for nearly two thousand years.

Mr. Dixon also estimates that in the Lothian coal-field 81·7 per cent. of the available coal occurs in seams which are 24 in. and upwards in thickness.

Mr. John Gemmell, who assisted Mr. Dixon in the Eastern Division of Scotland, has kindly informed us that out of the estimate of 2,520,311,573 tons just referred to, an amount of about 2,365,000,000 is considered to be contained in the Mid-Lothian coal-field.

It is to be remembered, however, that at present comparatively few seams—only the best and the thickest—can be profitably worked, and that the depths of some of the coals in the central flatter part of the basin are very great.

Mr. Martin stated a few years ago§ that the Great Seam at Niddrie, whose total thickness is 7 or 8 ft., is only worked there for the sake of the cannel coal, about 2 ft. thick. The bottom part of the seam consists of 3 ft. of common coal which is left intact.

* "Mines and Quarries: General Report and Statistics," for 1903 and for 1905. The output for the whole of Scotland in the latter year amounted to 35,839,297 tons.

† "Final Report of the Royal Commission on Coal Supplies," 1905, pt. vii. p. 7.

‡ In estimating this amount no deduction appears to have been made on account of the possible continuation seaward of the Pentland fault and the folds near it.

§ "First Report of the Royal Commission on Coal Supplies," 1903, vol. ii. p. 69.

In the Niddrie Collieries the Great Seam has been proved to a depth of 2756 ft. below the surface, being nearly flat at this depth, and the lower seams must of course be correspondingly deeper. Near the centre of that part of the basin which lies immediately north of the Sheriffhall fault, the general dip is towards the south, and the depth of the Great Seam may in places be nearly 3500 ft., but on the south side of this dislocation its depth is of course considerably less. In the Newbattle cross mine of the Lady Victoria Pit, Newtongrange, the Parrot Coal has lately been cut at a depth of about 2000 ft. below Ordnance Datum. In the Carrington Dook of the same colliery this seam is somewhat higher, chiefly in consequence of the north-easterly faults with downthrow to the north-west that pass through Newtongrange, and about a quarter of a mile W.N.W. of Aikendean, perhaps a mile on the east side of the centre of the basin, it is about 1746 ft. below Ordnance Datum (or about 2150 ft. below the surface), and lying at gentle angles.

On the western side of the basin many of the seams are very steeply inclined where they are near the surface and for some considerable distance down. Unfortunately coals dipping at a high angle are more costly to work than flat seams. A pit sunk to a seam which is very highly inclined opens out a comparatively small area of workable coal. Only coal to the rise is available, and though cross-cut mines may connect a number of seams at the pit bottom, still these entail great expense. Moreover, coal-cutting machines cannot be used where the seams are steep. On the west side of the basin, until it was possible to go down deep enough * to get the edge coals in a flat position, it was impossible to work these seams with economic advantage.† It is, also, to be remembered that in the flatter beds near the centre of the basin great quantities of water are often encountered, which increase the working costs.

It is evident that the strata in all the Carboniferous groups have a general tendency to diminish both in thickness and in coal contents, as they are traced from the north-west side of the basin either in a southern or eastern direction (see p. 159). Hence we may expect that the deeply covered untapped seams of the Edge Coal series, which lie near the centre of the syncline between Musselburgh and Barleydean, will on the average be intermediate in thickness between those in the adjacent parts on either side. It is important to bear in mind that both at Arniston Mains and at Penicuik the Edge Coal group is only about half as thick as at Niddrie, and that the seams belonging to this division which are exposed on the south side of the Vogrie-Temple fault do not offer much promise of profitable mining. It appears that on the coast of Fifeshire the Edge Coal group is not so well developed as near Joppa,‡ and therefore its general under-sea development cannot be expected to be so good as at the latter locality.

The Coal Measures also show a tendency to decrease in thickness as we pass in a southern or eastern direction from the north-west

* R. Bald, in his "Observations on the Coal-Field and Accompanying Strata in the Vicinity of Dalkeith, Mid-Lothian," *Edin. Phil. Journ.*, 1827, vol. iv. p. 115, states that at that date no pit in Scotland exceeded 80 fms. in depth.

† R. Martin, "Coal-Mining in the Musselburgh Coal-Field," *Trans. Edin. Geol. Soc.* vol. viii. p. 379.

‡ "Final Report of the Royal Commission on Coal Supplies," pt. vii. p. 2.

side of the basin, and, besides, the higher seams in this group are not preserved on the south side of the Sheriffhall fault. The eastern area of the Coal Measures between Dalkeith and Carrington has been much less mined than the western, but parts of it are being approached by underground roads in the Polton and Whitehill Collieries. On the coast of Fifeshire the coal seams of the Coal Measures are stated * to be better developed on the average than on the Mid-Lothian shore, and therefore they may be expected to be generally well developed in the invervening under-sea areas.

As already stated, it is only a few of the best coals which are now being mined.† The following list, drawn up from information supplied by the various mining companies, shows briefly the different seams which are now or have recently been worked, together with the usual thicknesses and qualities:—

Name of Colliery.	Name of Seam.	Thickness.	Class.	Quality.
		Ft. In.		
Olive Bank	Splint	5 0	House and Gas	Good
New Craighall ..	Nine-foot, Soft portion (Jewel)	5 0	House	„
„	Nine-foot, Splint portion..		Steam and Gas	
„	Fifteen-foot (Ell)	8 0	Steam	Fair
Woolmet..	Five-foot (Blackband) ..	—	House and Gas	Good
Whitehill & Polton..	Great	6 0	Steam	
„	Diamond	4 0	House	
„	Splint	3 0	Steam and Gas	
„	Jewel	2 9	House	
Niddrie ..	South Parrot, Cannel portion (Edmonstone Cannel) ..	2 0	Cannel	Good
„	South Parrot, Splint portion	2 0	House, Gas and Steam	„
„	Great, Cannel portion (No. 1 Cannel)	2 0	Cannel	„
„	Great, Common Coal portion	2 0	House & Steam	Fair
„	Stairhead (No. 3) Cannel..	5 0	Cannel	„
Burghlee, Ramsay Pit (Loanhead) & Roslin ..	South Parrot	1 3	Household	Good
	Splint	1 0	„	Fair
	Flex	3 6	Steam	
	Dryden Parrot	1 6	Gas	
	Great	4 10	Steam	
„	Stairhead	2 10	„	
„	Gillespie	2 10	Household	Fair
„	Blackchapel	3 2	Steam	
„	Peacock	3 0	„	
„	Glass	2 0	Household	Fair
„	No. 1 Ironstone Coal ..	1 0	Parrot	Wild
„	Beattie	2 10	Household	
„	Craigie or Corbiecraig ..	4 0	„	Fair
„	Corbie Splint	1 4	„	
„	South Coal..	4 0	„	
„	North Coal	3 0	„	Best
„	North Greens	3 2	„	„
Penicuik ..	Stairhead	3 3	Steam	Fair
„	Peacock	2 9	„	„
„	Corbie Splint	2 6	Gas	Good
„	Corbie Jewel	4 6	Steam & House	„

* "Final Report of the Royal Commission on Coal Supplies," 1905, pt. vii. p. 2.
† Sometimes only the best portion of a seam, the inferior portion being left.

Name of Colliery.	Name of Seam.	Thickness. Ft.	In.	Class.	Quality.
Arniston	Great .. .. 5 ft. to	6	0	Steam	Good
„	Diamond (Dundas) 1 ft. 11 in. to	2	0	House	Excellent
„	Splint .. .. 4 ft. to	5	0	„	Good
„	Kailblades .. .. 4 ft. to	5	0	Steam	„
„	Little Splint 1 ft. 11 in. to	2	1	House	„
„	Parrot, Jewel portion 2 ft. to	2	1	„	Excellent
„	Parrot, Parrot portion 7 in. to	0	9	Gas	„
Newbattle	Great	6	6	Steam	Good
„	Diamond	1	11	House	Excellent
„	Coronation..	3	0	„	Good
„	Splint (Bryans Splint) ..	4	0	House or Steam	„
„	Kailblades	4	3	Steam	„
„	Parrot, Jewel portion ..	1	4	House	Excellent
„	Parrot, Parrot portion ..	0	9	Gas	Rich
„	Parrot, "bottoms" ..	1	3	„	Good
Wallyford & Carberry	Great	9	0	Steam	„
„	Jewel	3	6	„	„
„	Parrot Rough	3	9	House	„
„	Four-foot	3	0	Steam	„
„	Five-foot	3	6	„	„
Preston-grange..	Main (Great)	7	0	House	Fair
	Clay Seam Coal 2 ft. 6 in. to	3	0	Steam	„
„	Jewel .. 3 ft. 6 in. to	4	0	House	Good
„	Beggar .. .. 3 ft. to	3	6	Steam	Fair

It is to be noted that two of the best coals—the North Greens and the South Parrot—on the west side of the basin, occur outside the two main coal-bearing groups. Inquiry is often made about the probable position of the North Greens on the east side of the basin, but it is very doubtful whether this coal exists there in a workable condition. Its position appears to be between the thick Limestone No. 2, which crops out at D'Arcy and Cousland, and the underlying limestone which was formerly quarried near the head of the Tyne Water, but near D'Arcy a bore put down to a depth of 116 ft. beneath Limestone No. 2 is said to have pierced no coal except a thin one at a depth of about 11 ft.

The South Parrot Coal is perhaps represented on the east side of the basin by a parrot shale, at least a foot thick, cropping out in the Gore Water between Limestones No. 4 and No. 5, which was formerly worked to a considerable extent as a gas producer. In about the same position also, in the old Cowden Cleugh Quarry, in the wood south of Langside Head, east of Dalkeith, parrot shale is seen from 6 to 10 in. thick, together with another slightly higher coal which also contains some parrot. The lower seam, which has been analysed by Dr. Pollard, leaves too great a percentage of ash to be of much value. The results of the analyses are given on the following page, together with those of another parrot shale exposed in the Crossgatehall railway cutting. The latter

shale is 8 ft. thick and is included in the Lower Limestone group.*

	Moisture.	Volatile Matter.	Fixed Carbonaceous Matter.	Ash.	Colour of Ash.	Total of Sulphur.
Cowden Cleugh Parrot Shale ..	6·07	49·62	25·44	19·07	Brownish white	1·68
Crossgatehall .. Parrot Shale ..	7·46	32·89	28·89	30·76	Pinkish white	·85

The Parrot Rough Seam of Whitehill and Polton was formerly distilled for oil at Dalhousie and Whitehill, and it is stated that at Whitehill it yielded about 40 gallons of crude oil per ton. It was also formerly used at the Edinburgh and Leith Gas Works, and is still used at the village gas works at Rosewell, together with an admixture of the Splint Coal. Mr. Herring, the manager of the Edinburgh and Leith Works, states that it is a fairly productive cannel of its class and yields a gas of 25 to 27 candle-power, but that the resulting coke is quite useless for fuel purposes, so that the seam cannot now be considered an economic gas-producing material.

Even the best parrot or cannel seams have considerably depreciated in value in recent years, owing to the introduction of incandescent lights and new methods of enriching, by the use of oils, the gases made from ordinary coals.

In the Niddrie Collieries thin blackband ironstones accompany the parrot portions of the Great and Stairhead Seams, and both are wrought with the coals and are sent to Shotts to be smelted. The ironstone with the Great Seam is about 8 in. thick, while that with the Stairhead is divisible into two portions, an upper 6-in. blackband of good quality and a lower 4-in. blackband of inferior quality. In the Loanhead and Penicuik collieries valuable seams of blackband ironstone are, or have been recently wrought. The upper or No. 3 Ironstone lies 12 ft. above the Great Seam and is divided into two parts by a thin gas coal. The middle ironstone (No. 2) is 2 ft. 7½ in. thick, and occurs 22 ft. below the Stairhead Coal. The lower or No. 1 Ironstone lies 16 ft. below the Glass Coal, and its topmost portion is a clayband ironstone.† The upper and the lower ironstones are still worked at Loanhead by the Shotts Iron Company, the calcined ore being taken by rail to their ironworks at Shotts.

The total output of ironstone in Mid-Lothian in the year 1903 amounted to 21,775 tons, and in 1905 to 28,697 tons.‡

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* For further particulars of the geological position, refer to p. 193.

† For further details of these ironstones, see pp. 202-211.

‡ "Mines and Quarries: General Report and Statistics," for 1903 and for 1905.

ANALYSES OF CERTAIN COALS IN THE MID-LOTHIAN BASIN COMMUNICATED BY VARIOUS MINING COMPANIES.

	Seam.	Specific Gravity.	Volatile Matter.				Coke.				Heating Power.*	Cubic Feet of Gas from One Ton.	Illuminating Power of Gas.†	Analysed by
			Gas, Tar etc.	Sulphur.	Water.	Totals.	Fixed Carbon.	Sulphur.	Ash.	Totals.				
Upper Limestone Group. Coal Measures.	Salters, New Craighall ..	1·25	35·69	0·46	14·85	51	43·42	0·44	5·14	49	6·74			
	Splint (Nine-foot), New Craighall	1·25	34·72	0·37	11·79	46·88	45·79	0·43	6·9	53·12		9,135	15·20	Messrs. Tatlock and Thomson.
	Soft portion of above coal, New Craighall Jewel ..	1·25	36·09	0·36	14·15	50·50	46·98	0·36	2·16	49·50	7·12			,, ,,
	Fifteen-foot (Ell), New Craighall	1·30	36·07	0·28	14·00	50·35	46·07	0·28	3·30	49·65	7·10			,, ,,
	Five-foot, Woolmet	1·19	36·75	0·58	9·20	37·33	51·02	0·20	2·25	53·47	13·36	11,160	21·85	,, ,,
	Great, Whitehill		33·88		3·48		53·71	0·86	8·07	62·64				Geo. R. Hislop.
	Splint, Polton		31·97	0·24	13·66	45·87	48·95	0·62	4·56	54·13				Stevenson Macadam.
	Splint, Whitehill	1·310	38·55	0·23	10·28	49·06	48·34	0·44	2·16	50·94				Robert Mitchell.
	Jewel, Polton		26·62	0·15	13·86	50·63	54·72	0·39	4·26	59·37				Stevenson Macadam.
	Jewel, Whitehill		27·51	0·26	12·41	40·18	55·60	0·28	3·94	59·82				,, ,,
	Edmonstone Cannel, South Parrot	1·259	45·24	0·46	5·73	51·45	42·53	0·29	5·73	48·55		12,530	31·62	Geo. R. Hislop.
		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*i*	*k*	*l*	*m*

Edge Coal Series.

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*
Great Seam (No. 1) Cannel, Niddrie		47·59	0·43	4·00	42·02	45·30	0·27	2·41	47·98	13·07	12,330	32·45	„ „
Stairhead (No. 3) Cannel, Niddrie		35·50	0·50	5·30	41·30	52·20	0·33	6·17	58·70	12·27	10,805	27·57	„ „
Carleton, Niddrie	1·273	28·68		12·15	40·83	56·26	0·47	2·44	59·17	13·28	9,893	18·74	Stevenson Macadam.
Corbie Splint, Penicuik ..	1·258	37·78	0·56	9·10	47·44	48·39	0·17	4·00	52·56	12·69	10,750	23·45	Geo. R. Hislop.
Corbie Jewel, Penicuik ..	1·216	33·59		9·50	43·09	53·38	0·59	2·94	56·91	13·041			„ „
Dundas (Diamond), Arniston Colliery	1·273	36·57	0·25	10·64	47·46	51·11	0·04	1·46	52·57				J. Falconer King.
Kailblades, Arniston Colliery	1·265			9·82	36·40			2·72	63·60	13·09			Thomas Hughes.
Cannel portion of Parrot Seam, Arniston Colliery ..	1·192	52·19	0·69	1·32	54·20	42·48	0·22	3·10	45·80		14,135	37·36	Geo. R. Hislop.
Great, Newbattle Colliery ..	1·254	29·13		7·85	36·99	60·77		2·24	63·01				Stevenson Macadam.
Diamond, Newbattle Colliery	1·257	31·83		6·97	38·8	60·08		1·12	61·2				„ „
Bryans Splint, Newbattle Colliery	1·322	31·32	0·25	9·87	41·19	55·02	0·36	3·43	58·81	13·38	10,520	15·45	Ivison Macadam. Robert Mitchell.
Kailblades, Newbattle Colliery	1·255	29·04		6·94		62·69		1·33	64·02				Stevenson Macadam.
Jewel portion of Parrot Seam, Newbattle Colliery		39·13	0·31	1·97	41·41	55·72	0·31	2·56					„ „
Cannel portion of Parrot Seam, Newbattle Colliery	1·175	49·67	0·56	1·14	51·37	44·06	0·24	4·33			13,720	35·24	Geo. R. Hislop.
"Bottoms" of Parrot Seam, Newbattle Colliery ..	1·265	36·04	0·51	6·92	43·47	52·86	0·32	3·35			10,830	23·25	Jas. D. Smith.

* Represented by the number of lbs. of water at 212° F., which can be evaporated into steam by 1 lb. of the coal.
† Represented by the number of standard sperm candles to which 5 cubic ft. of the gas are equal.

Bo'ness and Bathgate.—Coal-mining is the most important industry carried on near Bo'ness and Bathgate, and the shipping trade of the former town is also mainly connected with mining, the harbour being conveniently situated for the export of coal from many distant pits, as well as for the import of pit props and timber.

The northern part of this coal-field is said to have been partly wrought by the monks of Holyrood about the end of the twelfth century. The coal seams that were capable of being profitably worked in the area between Bo'ness and Linlithgow appear to have been already exhausted for the most part, except near Kinneil, where the workings reach a depth of more than 1560 ft. below the sea-level, and even in this region it is to be feared that the coals may soon deteriorate or disappear as they are followed towards the dip, in the direction of the North Hainings deep bore, in which no workable seam was found (see p. 136). How far westwards the deterioration extends is not known, but some hope may be gathered from the fact that the coal-bearing group referred to is entirely free from cotemporaneous volcanic intercalations when it rises to the surface again along the west side of the Lanarkshire basin.

Three collieries are now working on the shores of the Forth, and it is expected that a further development of mining under the Firth of Forth will shortly be witnessed, new sinkings having recently been in progress at Kinneil, Bridgeness and Carriden. Operations under the Forth are, however, liable to sudden interruption owing to the presence of a deep preglacial hollow—probably part of the old valley of the Forth *—at the sides of which the coals crop out against boulder clay. The outcrop of the Easter Main Coal against the boulder clay, on the south side of this hollow, strikes about east and west for nearly half a mile at a distance of rather more than 600 yds. north of Bridgeness Pier, and at a depth of about 500 ft. below the sea. The corresponding outcrops of the Lower Parrot and Ironstone Seam and of the Red Coal have also been found, and it is clear that the hollow referred to makes a big bend towards the south as we follow it up stream. But fortunately nothing except boulder clay of a stiff impervious character has hitherto been found in the hollow. This deposit is overlain by a bed of plastic waterproof clay, which Mr. Cadell states "can bend down when the rock subsides during the process of working the coal seams below, on the long wall system." †

The Wood Coal, under the Arden (Dykeneuk) Limestone, is nearly three feet thick to the west of Bo'ness, and does not appear to have been worked except in shallow mines, but it is only a second class coal.

The washings from each of the seams—the Smithy and the Six-foot—which are now mined at Kinneil are finely powdered and coked in ovens at the Snab Pit. The East Main Coal of Carriden is described

* Already partly described by Mr. Cadell in his description of the "Surface Geology of the Estuary of the Forth round Borrowstounness" (*Trans. Edin. Geol. Soc.*, vol. iv. p. 2), and again in a "Note on the Buried River Channel of the Almond" (*Trans. Edin. Geol. Soc.*, vol. viii. p. 194).

† "Submarine Coal-Mining at Bridgeness," *Trans. Fed. Inst. Min. Engineers*, 1898, vol. xiv. pt. ii. p. 237.

by Messrs. Tatlock and Thomson as an excellent coking coal, giving a hard and durable coke of the finest quality, but it has never been coked at the pit.

At Bathgate the valuable parrot and ironstone of the Balbardie Seam is chiefly sought after, but to the south, at Blackburn, none of the proved coals contains parrot, and ordinary bright coals are alone mined. The volcanic rocks here, as near Bo'ness, appear to increase in importance westwards, to the dip, for a certain distance (see p. 127). The absence of workable coals in Vivian's bore (see p. 138) is probably due, however, to this bore having passed through the large east and west fault, by which the upper more productive part of the coal-bearing group is faulted out.

In the Mosshall and Woodmuir district the collieries at present working are Foulshields, Loganlee and Lower Woodmuir; Stoneyburn and the pits between Blinkbonny and Miller's Moss being all dismantled.

The following list, drawn up from information supplied by the various coal-mining companies, shows briefly the different seams which are now, or have recently been worked in the Bo'ness and Bathgate district, together with their average thicknesses and qualities. The Cobbinshaw Coal, placed at the end of the list, lies in a stratigraphical position considerably below the others, and has often been correlated with the Hurlet Coal of Renfrewshire:—

Name of Colliery.	Name of Seam.	Thickness.	Class.	Quality.
		Ft. In.		
Carriden ..	Six-foot	4 6	Steam and Gas	Fair
„	East Main	4 0	Steam, House & Gas	Good
„	Smithy	2 10	House and Gas	First class
Bridgeness & Grange	Grange Splint (Red Coal)	2 10	Gas	Good
	Cannel (Lower Parrot and Ironstone)	1 2	„	„
„	Six-foot	6 0	House	Fair
„	Main Splint (East Main) ..	3 0	House & Steam	Good
„	Ocean Wallsend (Smithy)	2 10	House	„
Kinneil ..	Six-foot : coking gas coal ..	4 0	Coking, Gas	Very good
„	„ cannel	0 6		„ „
„	Smithy .. 3 ft. 6 in. to	3 9	Coking, Gas and House	„ „
Balbardie	Balbardie Seam : cannel 5 in. to	0 10		First class
„	„ „ ironstone 3 in. to	0 5	Blackband	
„	„ „ coal 1 ft. 5 in. to	1 6	Gas, Coking, House & Steam	Good
„	Jewel .. 3 ft. 6 in. to	4 0	Gas, Coking, House & Steam	„
„	Main .. 5 ft. 6 in. to	6 0	Gas, Coking, House & Steam	„
Riddochhill	Jewel	3 6	Steam and Gas	Fair
„	Main	4 3	„ „ „	„
Mosside ..	Balbardie : gas coal ..	0 11		
„	„ ironstone ..	0 3		
„	„ coal	1 9	House	Fair

Name of Colliery.	Name of Seam.	Thickness.	Class.	Quality.
		Ft. In.		
Mosside	China : coal	1 9	Steam and Gas	Fair
„	„ wild gas	0 10		
„	Jewel	3 3	Steam and Gas	Fair
„	Main	5 9	„ „ „	„
Boghead ..	Balbardie : gas coal ..	0 10		
„	„ ironstone ..	0 2½		Fair
„	„ coal	1 8	House	„
„	China : coal	1 5	Steam and Gas	„
„	„ gas coal	0 6		Good
„	Woodmuir	2 0	Steam and Gas	Fair
„	Jewel	3 6	„ „ „	„
„	Main	5 9	„ „ „	„
Woodmuir	Woodmuir Main or China	2 2	House	„
Loganlea & Foulshiels	Woodmuir Smithy	2 3	Steam	„
„	Lady Morton	3 0	Steam and Gas	Medium
	Wilsontown Main	4 0	Steam & House	Good
Cobbinshaw	Cobbinshaw Coal	4 0		Inferior

The Cobbinshaw Coal—the last in the foregoing list—is the only coal now being worked in the Calciferous Sandstone series, and it is only mined now at Cobbinshaw itself—though formerly in many adjoining localities. Though an inferior coal, it is found convenient to use it in the limekilns close at hand.

The analyses of various coals worked in this district have been kindly communicated by the mining companies, and some of the results are shown in the accompanying table (page 347).

The Kinneil iron furnaces ceased operations about twenty years ago, and no ironstone is at present mined near Bo'ness. It is stated, indeed, that the Lower Blackband Ironstone, which was once so highly prized, has been entirely worked out, but that parts of the Upper Blackband Ironstone remain untouched, even in easily accessible positions where it is of good quality.

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West Calder, Uphall, Broxburn and Dalmeny.—The Houston Coal, in the Calciferous Sandstone series, which lies in some places at least as much as 1000 ft. below the base of the Carboniferous Limestone series, was formerly very extensively worked in shallow mines in the basins of Houston House, Oatridge, Hillend and Ecclesmachan, as well as near Drumforth, Threemiletown, Wester Auldcathie and on the west side of the canal at Winchburgh. In later times, during the keen competition between the Scottish and American oils, three oil companies opened out the seam again, with the hope of procuring a cheap class of fuel, and thus reducing their working expenses, but the experimental works were not successful. It is a pyritous seam of inferior quality, with a number of shale partings and a bad roof and soft pavement. Its thickness varies greatly from place to place, amounting to six feet at West Binny, Drumcrosshall, and Baads, near West Calder. At the last place it was worked sixteen years ago in connection with the oil-shale. The pavement is here soft fireclay, and when mined in pillars it was found impossible to continue that system of working, as the pressure

Seam.	Specific Gravity.	Volatile Matter.				Coke.				Heating Power.	Cubic Feet of Gas per Ton.	Illuminating Power of Gas.	Analysed by
		Gas, Tar etc.	Sulphur.	Water.	Totals.	Fixed Carbon.	Sulphur.	Ash.	Totals.				
East Main, Carriden	1·30	33·78	0·16	1·43	35·38	62·18	0·30	2·14	64·62	8·86	10,195	17·20	Messrs. Tatlock and Thomson.
Grange Splint (Red Coal), Bridgeness and Grange	1·30	30·02	0·22	1·46	31·70	63·58	0·47	4·25	68·30		9,651	16·50	R. R. Tatlock.
Grange Cannel (Lower Parrot and Ironstone), Bridgeness and Grange ..	1·28	31·55	0·50	1·20	33·25	59·67	0·34	5·54	65·55	12·57	11,120	30·15	Geo. R. Hislop.
Main Splint (East Main), Bridgeness and Grange	1·282	30·77	0·23	2·04	33·04	64·21	0·29	2·46	66·96	14·75			William Wallace.
Ocean Wallsend (Smithy), Bridgeness and Grange	1·274	30·53	0·60	2·80	33·93	62·37	0·60	3·10	66·07	14·67			John Clark.
Cannel portion of Six-foot, Kinneil ..	1·251	38·26	0·32	1·44	40·02	53·91	0·18	4·45	58·54	12·69	13,412	34·51	Geo. R. Hislop.
Coking Gas Coal (Smithy), Kinneil ..	1·266	28·16	0·26	3·45	31·87	61·42	0·15	3·11	64·68	13·08	11,620	22·85	„ „
Balbardie Shale (shaly cannel), Balbardie Seam, Balbardie	1·346	34·04	0·31	1·75	36·10	41·73	0·22	20·20	62·15	9·27	10,830	34·10	„ „
Balbardie Cannel (without shaly cannel), Balbardie Seam, Balbardie ..	1·175	47·62	0·36	1·58	49·56	42·96	0·17	5·73	48·86	12·12	14,150	36·42	„ „
Easton Cannel (cannel and shaly cannel mixed), Balbardie Seam, Balbardie	1·234	43·08	0·38	1·24	44·70	43·88	0·17	10·01	54·06	11·19	13,440	35·20	„ „
Balbardie Coal (bright coal), Balbardie Seam, Balbardie	1·257	25·89	0·28	7·23	33·40	57·85	0·18	1·34	59·37	13·43	10,805	20·15	„ „
Main (gas) Coal, Riddochhill	1·280	25·91	0·42	7·50	33·83	55·69	0·26	2·72	58·67	12·98	10,630	21·51	„ „
No. 2 Cannel (China), Mosside.. ..		32·55	0·48	4·80	37·83	38·07	0·36	18·94	57·37	9·20	10,970	30·38	„ „
Jewel (Ell), Mosside	1·28	31·67	0·24	8·78	40·69	54·77	0·24	4·30	59·31	12·45			John Clark.
Main, Mosside	1·29	32·00	0·52	7·38	39·90	53·90	0·52	5·68	60·10	12·20			„ „
No. 1 Cannel (Balbardie Seam cannel), Boghead	1·307	43·49	0·44	2·34	46·27	43·44	0·13	7·82	51·39	11·65	13,640	35·34	Geo. R. Hislop.

on the roof squeezed the pillars down into the pavement, while the roof was so bad that a foot and a half or two feet of the seam had to be left to support it, thus entailing the loss of nearly half of the available coal.* J. S. G. W.

Brick Clay and Fireclay.

Mid-Lothian Coal-Field.—Bricks are made at various collieries, including Whitehill, Arniston, Newbattle and Prestongrange, the material used being either shale (blaes) procured in "brushing" the underground roads, or underclay, or mixtures of these materials. At Prestongrange, one of the coals, called the Clay Seam, is chiefly worked for the sake of the underclay, about two feet thick, which underlies it. At Whitehill, firebricks and sewage pipes etc., are made of the fireclay that underlies the Great Seam, while building-bricks are made of blaes got near the position of the Splint and other coals. At Arniston Colliery the best clay is said to be that which underlies the Kailblades Coal. Some fireclay procured from the partings in the Fifteen-foot Coal is sent from Newcraighall Colliery for use in the Portobello Brickworks. More than thirty years ago, fireclay a little below the Index Limestone was used at Joppa; the material procured is said to have been conveyed to the Bankpark Fireclay Works, Tranent, and to have been there manufactured into firebricks, pipes and gas-retorts.

The clay formerly worked at Smeaton for making bricks and tiles occurs below the level of the highest raised beach, and is probably of much the same character as that at Portobello (see p. 349), but it is not now exposed.

Finely laminated glacial clays exposed near Eskbank railway station are said to have been formerly dug for brick-making. Similar clays have also been worked in the old clay-pits near Newtongrange.

The mottled red, brown and purple clays found in the Coal Measures on the north side of the Sheriffhall fault at Dalkeith have a close resemblance to the marls that lie above the *Etruria* beds of North Staffordshire, and are so much used for the manufacture of the Staffordshire blue bricks. Samples of this clay have, at the request of the Geological Survey, been moulded and burnt into miniature bricks (4·3 in. × 1·9 in. × 1·45 in.) by Mr. Dunnachie, of the Glenboig Fireclay Company. Professor R. Stanfield, of the Heriot Watt College, has tested these bricks, and states that the average crushing load of the two is 5·31 tons per square inch. He adds, "The samples resemble, in appearance and strength, the well-known Staffordshire blue brick, which has an average crushing strength of about 2·3 tons per square inch. The usual thickness of a brick is 3 in., and if the above samples had been of similar dimensions instead of 1·45, I should have expected the crushing strength to be at least equal to that of the Staffordshire variety. The material appeared to be homogeneous in character, and the samples were well burnt. The Staffordshire blue brick is used for positions requiring great strength: piers, foundations, abutments, etc. Its power of absorbing water is

* H. M. Cadell, "The Geology of the Oil-Shale Fields of the Lothians," Anniversary Address, 1890, *Trans. Edin. Geol. Soc.*, vol. viii. p. 131.

very low, and this property renders it most suitable for such positions."

Some of the coal-seats are very siliceous and closely resemble the ganisters of the West Riding of Yorkshire, which are so much in request for the manufacture of Silica bricks. A bed a little above the base of the Coal Measures east of Roslin Castle, and another, outcropping in the North Esk about half a mile east of Auchendinny, may be mentioned as examples of these siliceous varieties, but the former is only about a foot thick, and the latter two feet. A sample of the latter has been analysed by Dr. Pollard and gave the following result:—

SiO_2	96·98
TiO_2	0·51
ZrO_2	0·08
Fe_2O_3	0·38
Al_2O_3	1·43
CaO	0·18
MgO	0·12
K_2O	0·20
Na_2O	0·03
Li_2O	trace
H_2O, at 105° C.	0·03
H_2O, above 105° C.	0·44
Organic matter	trace
	100·38

The microscopic examination by Mr. Thomas of a specimen of this bed disclosed the presence of zircon, tourmaline, rutile, anatase and corundum (?).*

It is to be noted that none of the clays in the Roslin Sandstone series is now worked, nor do they appear to have been formerly wrought, though some are very thick (Plate VII. facing p. 245). The steepness of the beds near the crop on the west side of the basin would no doubt be adverse to an economical working. On the eastern side, however, their dip is comparatively gentle, varying from 10° to 15° east of Musselburgh.

Among the basal beds of the Coal Measures thick beds of fireclay are found below the Broomieknowe Sandstone (see p. 266) in the area near Roslin Castle.

A brick-field was started some years ago on the east of Mayshade, Loanhead, to manufacture bricks from boulder clay and blaes, but the undertaking proved unsuccessful.

Portobello.—The stoneless clay of Portobello, which appears to form part of the 100-ft. raised beach deposits, has been extensively dug for many years and used for the manufacture of bricks, tiles, chimney pots, flower pots etc. It has been proved by boring to extend to a depth of 100 ft. A few feet of it near the surface contains thin layers or patches of sand, which render it the more suitable for making bricks. At greater depths it is more pure and plastic, and fit for pottery ware, but is also adapted for brick-making when mixed with sand or ashes.

Winchburgh and East Calder.—Several small brick and tile works were at one time scattered over West Lothian where primitive

* "Summary of Progress" for 1904, *Mem. Geol. Sur.*, p. 57.

hand methods of manufacture were employed. These are now all superseded by the large works at Winchburgh, Camps and Ecclesmachan, equipped with the most modern machinery. The materials used at the first two localities are boulder clay and blaes which are excavated together in about equal proportions. The large stones in the clay are thrown aside, and the mixed material is ground in a pug mill and then passed through the brick-making machines.

The brick-making machinery used in this district is that constructed by Bradley & Craven, and the kilns are either continuous burning Hoffman's, or those based on the Newcastle plan. These are intermittent and appear to be inferior to the continuous type.

Bo'ness and Bathgate.—At Foulshields Colliery a brickwork has lately been started. The material used is a mixture of shale brought from Cleland, and of boulder clay dug from a pit alongside the works, the clay being separated from the large stones. The brick-making machines are manufactured by Bradley & Craven, and the kiln used is based on the Newcastle plan, with five chambers, which, when in full working order, can turn out 10,000 bricks of good building quality per day.

Bricks and tiles are made from an alluvial clay west of Bathgate, and, a few years ago, an attempt was made to manufacture artificial sandstone from the drift sands. The process was a French one, and consisted in subjecting a mixture of sand, lime and asbestos, first to pressure, and then to the action of steam. By being pressed into moulds the mixture was shaped into bricks of any size required, which retained their form when subsequently heated by steam.

A bed of clay above the limestone at Whitebaulks was formerly wrought for brick-making.

Near the coast about a quarter of a mile north-east of Blackness, a bed of blaes within the Calciferous Sandstone series has formerly been dug, presumably for making pipes for field drains. It appears that a bed of calcareous ironstone, cropping out on the beach near the old blaes pit, was at one time used for making hydraulic lime. The ironstone is said to be overlain by an alum shale, also formerly put to a commercial use.* C. T. C., J. S. G. W., E. B. B.

Oil-Shale.

In view of the recent publication by the Geological Survey of the memoir on "The Oil-Shales of the Lothians" only a brief reference will here be made to the best oil-producing shales within the area.

The quality and thickness of the different seams of oil-shale show great variations throughout the region under description. At Cobbinshaw the richest seams are the Fraser and Fells Shales, the lower ones are not represented. In the West Calder district the Fells and Dunnet Shales are the best, while the Broxburn is of inferior quality. At Pumpherston the Dunnet and Barracks shales are the oil-producers. The Pumpherston group is now wrought only by the Broxburn Oil Co., on the north side of the Pumpherston anticline. The Broxburn Seam is rich at Broxburn, while the Fells is there too poor to work. In the Philpstoun district

* *Statistical Account of Scotland*, 1845, vol. ii. p. 50.

the Broxburn Shale is the only workable seam and the Dunnet is useless, while on the north side of the Ochiltree fault at Duddingston the latter is thick and of good quality. At Dalmeny the Broxburn Seam is the only oil-producer, the Fells being too thin to work. At Straiton the Dunnet is the best shale and is of excellent quality. On the north side of the Forth this seam is the only one known in the Burntisland district and is inferior.

Refineries are situated at Broxburn, Pumpherston, Oakbank, Addiewell and Uphall, where oil-shale is also retorted. In addition to these works retorting plants are in operation at Dalmeny, Niddry, Hopetoun, Philpstoun, Roman Camp, Deans, Seafield and Breich, and the crude oil is sent to the different refineries to be

Analyses of Shales from Granton, Hailes and Ravelston.

Localities, etc.	Crude Oil.		Sulphate of Ammonia.	
	Gallons per Ton of Shale.	Sp. Gr.	Setting Point.	Lbs. per Ton of Shale.
Granton shore. An average taken of many specimens	15·36	0·880	86° F.	18·8
Hailes Quarry, from 6 to 18 ft. above the Hailes Sandstone. Samples with fish remains taken across the 12 ft...	8·32		85°	20·89
Railway cutting 100 yds. above or south of Boag's Mill, Water of Leith, from a bed 1 ft. thick at the bottom of the shale	8		84°	25·09
Shales from Granton Harbour :—				
No. 1	7·68		86°	22·97
„ 2	3·20		85°	20·80
„ 3	16·00	0·876	85°	16·00
„ 4	13·44	0·870	86°	21·92
Wardie Shale, probably not far above the Craigleith Sandstone, 60 yds. slightly south of east of Ravelston Lodge on the south side of the new roadway parallel with and immediately south of the Queensferry Road. Specimen taken 2 to 3 ft. below surface of soil, and therefore weathered..	11·84	0·822		17·76
Six samples from 12 ft. of shale. Each sample represents a fair average of a thickness of 2 ft. From excavation for retaining wall on south side of Queensferry Road, 90 yds. east of Ravelston Lodge; now covered up :—				
No. 1, top 2 ft...	0·0			13·53
„ 2, next 2 ft...	2·25			16·70
„ 3, „ 2 ft...	12·8	0·899	83°	16·70
„ 4, „ 2 ft...	12·6	0·887	83°	16·70
„ 5, „ 2 ft...	12·8	0·886	79°	15·64
„ 6, „ 2 ft...	7·87	0·886	80°	14·60

manufactured into the various burning and lubricating oils and wax products. J. S. G. W.

Reference has already been made (p. 171) to the series of bores put down along the west side of the Mid-Lothian basin between Eight Mile Burn and Carlops and thence to West Linton. One oil-shale of good quality (the Carlops Shale) has been found in most of these bores, which probably represents the Dunnet Seam in the Straiton section, in the Calciferous Sandstone series. L. W. H.

Some of the oil-shales associated with the Granton Sandstone, Wardie Shales and Hailes Sandstone (see Chapter X.) have been analysed by Mr. D. R. Steuart of the Broxburn Oilworks, the results being given in the table on previous page. It should be stated that these shales are not considered to be workable at a profit at the present time.

Mr. Steuart has also added the following remarks: "These laboratory determinations of ammonia require to be doubled to give approximately a works result.

"The most of the samples were weathered and the results from fresh shale would no doubt be a good deal better. The shales from the paraffin oil manufacturers' point of view are worth investigation.

"The shales at present worked in Scotland give 23 to 27 gallons crude oil per ton and 40 lb. sulphate of ammonia, and 18 to 20 gallons crude oil with 50 to 60 lb. sulphate." C. B. C.

Silver, Lead and Nickel Ores.

Hilderston Mine (Sheet 31).—At the locality called Silvermine, about two miles N.N.E. of Bathgate, a vein occurs which is said to have contained filamentary native silver. The ore was worked in the time of James VI., and the old records* state that it proved rich down to a depth of 12 fms., but below this level down to 30 fms. the vein proved worthless.

The mine was explored between 1870 and 1873,† and a shaft was sunk to a depth of over 220 ft., but no native silver was discovered. The vein was found to lie on an east and west whinstone dyke, which branched from the north and south dyke exposed at the surface to the west of the mine. The veinstone is barytes. The beds forming the hanging wall of the vein measured vertically are:—

	Ft.
Surface, clay, stones	18
Sandstone	11
Fakes	37
Whinstone	16
Blaes	11
LIMESTONE (Petershill)	54
Marl	42
Marl and whin	36
	225

* Atkinson, "The Discoverie and Historie of the Gold Mines in Scotland," 1619 (Bannatyne Club, 1835); Sibbald's "Description of Scotland," MS. 15.1.1. Advocates' Library, Edinburgh, and Supplement to "Prodromus," MS. 33.5.19. *ibidem.*

† Aitken, "The Hilderston Silver Mine, near Linlithgow," *Trans. Fed. Inst. of Mining Eng.*, 1894, vol. vi. pp. 193–198.

Against the whinstone the vein is about 6 ft. in width, and consists entirely of barytes. Opposite the blaes the vein carried a little galena, and opposite the limestone a very little oxidised nickel ore and argentiferous galena, whilst on reaching the "marl" the vein practically disappeared.

A bore put down to a depth of 360 ft. below the metals found in the bottom of the pit proved "almost nothing except marl." It is probable that much of the marl, especially that referred to in the two last items of the section, is really volcanic ash, which is known to underlie the limestone.

About 60 yds. to the north there is a thin vein, which carries a little galena.

Goodchild * confirms the statement that the principal veinstone is barytes. Further, he adds that the galena occurs in scattered nests and crystalline masses, and that with it are associated niccolite, annabergite and erythrite. H. B. M.

Limestone.

Mid-Lothian Basin.—The Burdiehouse Limestone has been wrought opencast for at least a hundred years by a series of quarries between Straiton and Burdiehouse Mains, and also to the south of Pentland Mains. The quarries are now closed, on account of the heavy cover, but the stone is still obtained at Burdiehouse by a mine proceeding from the outcrop towards the dip, and at Straiton by a shaft 50 fms. deep. The stone is calcined, and the lime sold for building purposes and gas purification.

The outcrops of limestone along the arch of the anticline between Hillhead and Cousland, on the west side of the Coal Basin, are at present less worked than formerly. At West Houses it is being mined in a day-level by the Lothian Coal Company, and conveyed thence to the kilns at Bryans. At Cousland the Caledonian Portland Cement Company has lately erected plant for making Portland cement from a mixture of finely ground limestone, obtained from the adjoining quarries in the Middle Skateraw or No. 2 Limestone, and of finely ground shale (blaes), got from above the limestone in the same quarries. The composition of the limestone is said to be tolerably uniform, and is indicated by the following analysis:—

Carbonate of lime	94·77
Silica	0·88
Ferric oxide	1·63
Alumina	0·87
Magnesia	0·83
Combined water and loss	1·02
	100·00

The composition of the shale is said to be more variable,

* "Notes on the Minerals of the Hilderston Silver Mines, Linlithgow," J. G. Goodchild, *Trans. Edin. Geol. Soc.*, 1898, vol. vii. pp. 201–202.

but the following analysis* may be taken to represent the average:—

Silica	51·60
Ferric oxide	4·10
Alumina	21·12
Carbonate of lime	7·80
Magnesia	0·38
Soda	2·07
Sulphurous anhydride	0·22
Combined water and loss	12·71
	100·00

The ground-up materials are thoroughly well mixed together and pressed into bricks, which are then burnt in the kilns, and the resulting clinker is crushed and finely powdered in tube mills. Almost the whole process is managed automatically, and the composition of the mixture used is checked by frequent analyses.

The lower limestones are quarried on a considerable scale at Middleton and Esperston in the south-east part of the basin. The stone, which is of good quality, is burnt and ground for building and agricultural purposes.

Bo'ness and Bathgate.—No limestone is at present quarried or mined except at Cobbinshaw, Leven Seat and Charlestown. At the first-mentioned locality the Cobbinshaw-Hurlet Limestone produces a very superior lime, which finds a ready market in Edinburgh, Glasgow and the surrounding districts. The Charlestown Limestone was probably worked many hundred years ago. The tomb of Queen Margaret (*obit.* 1093), Dunfermline Abbey, is built of a coral limestone which has a resemblance to one of the beds in this quarry. The Charlestown Lime Works were started about the year 1760 by Charles, fifth Earl of Elgin. As many as eleven kilns were in operation at one time, and most of the lime was sent away by sea. Since the introduction of railways the trade has gradually fallen away, and now there are not more than two kilns burning, each of them capable of turning out from 20 to 25 tons of burned lime per day. For the past ten years the limestone has been got by mining, and the average output for the past three years is 6500 tons. The lime is principally used by builders and plasterers, and a considerable quantity of the ground lime is sold for agricultural purposes in the months of April and May. The following two analyses (1) of the limestone, (2) of the ground lime, together with the preceding notes regarding the Charlestown Limestone, were kindly supplied to us by Mr. William Black, the manager of the Lime Works:—

(1) *Analysis of the Charlestown Limestone.* (John Hunter, F.I.C.).

Carbonate of lime	83·58
Carbonate of magnesia	8·94
Silicate of magnesia	0·33

* Both these analyses and some of the other particulars are extracted from a pamphlet issued by the Company, in which the processes of manufacture, etc., are described.

Carbonate of iron	3·29
Iron oxide and alumina	1·18
Organic matter etc.	1·48
Sand	1·20
	100·00

(2) *Analysis of the Charlestown Ground Lime.* (John Hunter, F.I.C.).

Caustic lime	67·41
Carbonate of lime	6·13
Caustic magnesia	2·90
Silicate of magnesia	11·00
Iron oxide and alumina	5·20
Organic matter etc.	2·36
Sand	5·00
	100·00

The thick limestone of Petershill and Hillhouse was also quarried a very long time ago. It has been worked almost continuously for a distance of five miles along the outcrop, and was also followed underground, westward, to a considerable extent. Immediately north of Bathgate new quarries might be conveniently opened in this limestone, should an increased demand for lime arise in the future.

Limestones have also been wrought in the following, among other places:—

East Kirkton (Sheet 31) in the Calciferous Sandstone series.
South side of Addiewell (Sheet 31) in the Lower Limestone group.
Baads Mill „ „ „
West Kirkton (Sheet 31) „ „ „
Tartraven „ „ „
Whitebaulks „ „ „
Wairdlaw (Sheet 31) „ „ „
Dykeneuk, Kinneil (Sheet 31), in the Arden Limestone.
Carribber Glen (Sheet 31) in the Arden and Castlecary Limestone.
Blackhall (south of Bents Station) (Sheet 31) in the Castlecary Limestone.
Bowden Hill (Sheet 31) „ „ „
Avon Viaduct, below Kinneil Mill (Sheet 31) „ „ „
Craigenbuck * (Sheet 31) „ „ „

The mine (day-level) near the Avon viaduct was mainly used in providing limestone for the Kinneil iron furnaces.

Queensferry, Livingstone and East Calder.—The Burdiehouse Limestone is now mined at Harburnhead, Newpark and East Calder, and the rock produced is used for iron-smelting purposes, but in the past it was extensively mined at Dundas Lime Works, Port Edgar, also opencast on the shore east and west of Hopetoun House and on the east side of the Forth Bridge. Inland it was quarried and mined around Parkhead and North Newton. To the south-west it was worked along a line of shallow pits between Dechmont and Livingstone for local purposes. At Bellsquarry, two miles north-east of West Calder, the larger portion of the rock of good quality was removed from a small basin north of the Calder fault.

* This place is not named on the one-inch Sheet. It is 300 yds. south-east of North Hainings, and about two miles west of Bo'ness.

Near West Torphin, Murieston Water, a freshwater limestone supposed to lie below the Fells Shale has been quarried and burned, and is now mined in a pit by Messrs. W. Baird & Co. Ltd., for use in the Gartsherrie blast furnaces.

C. T. C., L. W. H., J. S. G. W., C. B. C., H. B. M., G. W. G.

Building-Stone.

Mid-Lothian Basin.—Among the sandstone quarries at present being worked are the following: two in the Coal Measures near Bonnyrigg, one in the Edge Coal group near East Houses, two in the Lower Limestone group near Gilmerton. The quarry on the south side of the road at Bonnyrigg is in the Broomieknowe Sandstone, and the other on the north side of the road is in a yellow sandstone, at least 60 ft. thick, which probably lies some distance above the position of the Great Seam of Whitehill. The sandstone in the old quarry on the east side of Gilmerton House lies immediately below a coal, which, in Bilston Burn, is situated 40 ft. below the Vexhim Coal. The quarry face shows 29 ft. of sandstone, soft and yellow or whitish, with numerous carbonaceous particles, which is separated into four divisions by partings of shale and fireclay. At the West Edge of Gilmerton a new quarry was recently opened in the same sandstone, but it is now abandoned.

The thick yellow sandstone — the Joppa Sandstone — which overlies Limestone No. 4 (Index) has formerly been extensively quarried near Joppa railway station, and also in the wood near Cowdenfoot, east of Dalkeith.

The Binny Sandstone was opened out some years ago by the Clippens Oil Company, in a quarry on the east side of the Edinburgh and Penicuik road, almost opposite to this company's offices at Straiton. The stone there is of excellent quality, but contains a considerable quantity of crude oil which was found in time to stain the surfaces of the dressed material, and the quarry has consequently been closed.

A yellow freestone of good quality is worked for local building purposes at Marfield Quarry, 3 miles south-west of Penicuik. The sandstone, of which at least 40 ft. is seen in the quarry face, lies in the Edge Coal series, between the Rumbolds Coal and the Great Seam.

Bo'ness and Bathgate.—Large freestone quarries are being worked near Kinneil, in a bed about 70 ft. thick, a little above the Index Limestone, which provided nearly all the material used in the recently erected town hall of Bo'ness. The best stone or "liver rock" is in the upper portion. At the east end of Bo'ness smaller quarries are opened out from time to time in the somewhat inferior freestone which forms the roof of the Red Coal.

Large quarries, now no longer in operation, have been made in the Calciferous Sandstone series at Kingscavil in a sandstone which is nearly 50 ft. thick and unbroken by partings. The rock is rather hard, the grains being partly cemented by calcareous and dolomitic matter, which is perhaps the cause of its disuse. It is durable, as shown by the old walls of Linlithgow Palace which are known to have been built of it.

At Cauldhame, another softer bed of sandstone is quarried, but owing to the presence of microscopic particles of pyrites, which decompose readily, the stone becomes iron-stained and disintegrates rather rapidly. On account of its softness this stone has, however, been much used locally for building purposes.

Edinburgh, Broxburn and West Calder.—Edinburgh is chiefly built of grey freestone procured from the Calciferous Sandstone series in the neighbourhood, but many of the old quarries have now been abandoned, partly in consequence of the increased cover of drift, and partly owing to the introduction of cheaper building material from a distance, which is softer and more easily dressed. Many of the recently erected buildings, such as the Antiquarian Museum, and the Caledonian Railway Station and Hotel, have been built of red Triassic sandstone brought from Dumfriesshire. The pale grey or buff freestone used in the Heriot Watt College and the new North British Station Hotel was, it is stated, chiefly carried from Hexham, Northumberland. Mr. George Craig * and Professor Hudson Beare † mention various other localities, in Northumberland, Lanarkshire and Fifeshire, which have furnished supplies for other buildings.

The Craigleith quarries appear to have been worked as early as the commencement of the seventeenth century, and for a long series of years the buildings of the New Town of Edinburgh, which still show little or no signs of weathering, were almost entirely erected with stone from these famous quarries. At present, however, comparatively little is being done in these quarries. The Bank of Scotland (reared in 1806), Donaldson's Hospital, the Scott Monument, the National Gallery and the Register House were all built of sandstone from the Binny Quarry, Uphall, which has proved remarkably durable. The Royal Scottish Museum and the Calton Prison were largely built of Hermand stone. On the south side of the city many of the new dwelling-houses are being built of sandstone, of a very faint pink tint, procured from the Upper Old Red Sandstone of Craigmillar.

The tabular list on next page, constructed from a more exhaustive one prepared by Mr. George Craig,‡ shows at a glance the physical properties, strength etc., of the more important Edinburgh building stones which are procured from the area under description. Those marked with an asterisk are not, it is believed, being worked at present. All except the Craigmillar stone belong to the Calciferous Sandstone series.

The terms, "density" and "specific gravity" at the head of two of the columns in the above list, have exactly the same meaning, but they have been used by different authorities, whose results differ slightly.

Professor Hudson Beare has also determined the coefficient of elasticity for pressure of certain sandstones within the area described, by measuring the compression undergone for a length of an inch and a half under different loads,§ both in the natural condition of these stones and on reapplication of the loads. His results are given in the list on page 359. It is stated that this coefficient was calculated for

* "On Building Stones used in Edinburgh: their Geological Sources, Relative Durability, and other Characteristics," *Trans. Edin. Geol. Soc.*, 1892, vol. vi. p. 254. Most of the subsequent particulars are also taken from Mr. Craig's paper.

† "Building Stones of Great Britain: their Crushing Strength and other Properties," *Proc. Inst. Civil Engineers*, 1892, vol. cvii. pt. i.

‡ *Op. cit.* p. 272.

§ *Op. cit.* pp. 24-25.

Stone.	Crushing Load per sq. ft.	Density.	Weight per cub. ft.	Absorption of Water.	Authority.	Tint.	Texture.	Nature.	Silica.	Carbonate of Lime.	Iron and Alumina.	Carbonate of Iron.	Carbonate of Magnesia.	Moisture and Loss.	Sulphur.	Oxide of Iron.	Specific Gravity.	Authority.
	Tons.		Lbs.	Per Cent.														
Binny * (Uphall)	569·1	2·16	135·1	5·22	Prof. Beare	Grey	Close	Medium										
Craigleith	861·9	2·22	138·6	3·61	Prof. Beare	Grey	Close	Hard	98·3	1·1	0·6						2·33	Parliamentary Committee.
Craigton						White												
Currie Glen, Borthwick, I.			150·5	4·22	S. Macadam			Medium	97·85		0·28	0·36	0·19	0·94			2·417	S. Macadam.
Currie Glen, II.			143·5	6·15	S. Macadam			Softer	97·66		0·26	0·34	0·22	1·24			2·300	S. Macadam.
Currie Glen, mean ...	284·5	2·10	131·4	5·34	Prof. Beare													
Dalmeny						Grey	Close	Medium										
Granton *						White	Close	Hard										
Hermand *...	457·4	2·28	142·6	4·70	Prof. Beare	Grey	Compact	Hard	94·68	1·56	0·92	2·19	0·27	0·38			2·445	S. Macadam.
Hailes	662·0	2·30	143·8	3·71	Prof. Beare	White	Close	Hard										
Hailes	459·7	2·29	143·2	4·76	Prof. Beare	Blue	Close	Hard										
Redhall, Slateford ...	662·0		143·8			Red and white	Close	Fine medium										
Ravelston *	855·8	2·26	141·1	2·93	Prof. Beare	Greyish white	Fine	Hard										
Ravelston,* Black Quarry	782·0	2·23	139·2	3·25	Prof. Beare	Very dark grey	Fine	Hard										
Craigmillar	982·0	2·46	153·6		Prof. Beare	Purplish white	Close	Hard										

both series of readings from the definition that the coefficient $= \frac{\text{stress}}{\text{proportional strain}}$.

Name of Stone or Quarry.	Co-efficient of Elasticity for Pressure.		
	First Time Load Applied.	Reapplication of Load.	Range of Stress.
	Tons per sq. ft.	Tons per sq. ft.	Tons per sq. ft.
White Hailes ..	78,780	105,100	32·1 to 192·8
Blue Hailes ..	54,290	86,960	32·1 to 128·4
Binny	124,200	152,300	32·1 to 192·8
Hermand ..	150,100	191,900	32·1 to 128·4

Paving Material and Road Metal.

Mid-Lothian Basin.—Road metal is obtained from various limestones at Esperston, Catcune, Middleton and Fountainside, and from a large quarry in basic andesite at Silverburn, near Penicuik.

Bo'ness and Bathgate.—The dolerite intrusions of Kettleston and Carribber have been largely worked for paving stones and road metal in the vicinity of the canal, which furnishes a cheap means of export. The rock is fine-grained at the top of the quarries, becoming coarser deeper down. It is traversed by pink aplitic veins, rendering the stone unsuitable for setts and curbstones, but fortunately these are infrequent. The finer-grained variety known as the "blue," forming the marginal parts of the intrusion, is more durable than the coarse central parts.

The "leckstone" or picrite, which is quarried at Rusha and half a mile south of Blackburn, has an unusually low conductive power for heat, and has, for this reason, been long used in Scotland and the North of England, to line the soles of bakers' ovens.

The bands of dolerite etc., that come between the Red Coal and the Upper Ironstone of Bo'ness, are quarried for road metal in several places near the town, namely, a quarter of a mile north-west of North Bank, two thirds of a mile N.N.E. of Gardener's Hall, a quarter of a mile S.S.E. of the railway station and about half a mile south-west of Bridgeness Pier.

South of Linlithgow, road metal is supplied by the fine-grained columnar basalts where conveniently exposed. The roads around Blackburn have been for many years supplied almost exclusively from the Bowden Lime Company's quarry (dolerite) at West Craigs Station, outside the area described in this memoir.

Edinburgh, Broxburn and West Calder.—The andesite of Blackford Hill is quarried for road metal by the County Council of Mid-Lothian. The dolerite quarries at Ravelrig and Hannahfield, near Balerno, provide material of excellent quality, but so intersected by joints that no blocks larger than paving setts can be obtained. The small rock is hand broken for road metal. At Kaimes Hill

the County Council have a large quarry to supply material for the roads. Near Ratho there are large quarries in the dolerite sill, from which paving setts and road metal are procured.

North Queensferry and Inverkeithing.—The sill of quartz dolerite at North Queensferry and Inverkeithing is extensively quarried by three companies, the Tilbury Contracting and Dredging Company, Messrs. Alex. Brunton & Son, and the Carlingnose Granite Company, the total annual output of these three together amounting to about 165,000 tons, the bulk of which goes to London and other parts on the east coast of England. The Tilbury contracting and Dredging Company, with an annual output of about 100,000 tons, produce, among other things, a patented road material, called Tarlithic, and claim that, owing to the coarse grain of their rock, tar permeates it more readily than other finer-grained material, and therefore has a better "binding" effect. It is stated that three specimens, in the form of 3-in. cubes, from the St. Margaret's Quarry of this company, which have been tested by Messrs. David Kirkcaldy & Son, 99 Southwark Street, London, showed a mean crushing strength of 1077 tons per square foot.

The Battery and West Quarries of Messrs. Alex. Brunton & Son, whose annual output for the last ten years averages 45,000 tons, are said to have been worked for a hundred and fifty years, the stone, prior to the more general employment of concrete, being in extensive demand for dock and quay walls, breakwaters etc. The stone is still used in a lesser degree for sea walls, in cases where a face of concrete is unable to withstand destructive wave action. Other portions are utilised for copings, ashlar and building stone, but the major part is now in demand for road purposes, such as curbs, setts, channels and macadam, while the smaller sizes of the machine-broken stone are used for concrete.

In the Carlingnose Quarry, the top 40 ft. of rock is said to be much harder than the lower portion, and is used for paving setts, while the lower 40 ft. is chiefly made into kerbstones: all the small stone unfit for the above purposes is broken by machinery for road metal.

A considerable part of the road metal used is brought from quarries outside the area under description, some even as far away as Tinto Hill. The following list of road metal quarries within the area has been drawn up largely from information kindly supplied by Mr. Robb, County Surveyor for Mid-Lothian:—

Quarry.	Locality.	Name of Rock.	Order of Merit.
Barnton ..	Cramond ..	Olivine dolerite ..	1
Kaimes ..	Kirknewton ..	—	2
Ravelrig ..	Balerno	—	3
Torphin ..	Juniper Green ..	Basaltic lava ..	4
Blackford ..	Edinburgh ..	Fine-grained andesite	5
Auchinoon ..	Mid Calder ..	Hornfels and olivine dolerite	6
Hillwood ..	Ratho	Quartz dolerite ..	7
Craigton ..	Winchburgh ..	—	8
Ratho	Ratho	—	9
Lennie.. ..	Corstorphine ..	Olivine dolerite ..	10

From the first three quarries and from the fifth, large quantities of material are obtained. Besides the quarries in the above list, there are a few others shown below, without any arrangement in order of merit:—

Quarry.	Locality.	Name of Rock.
Craigiehill	Dalmeny Parish	Olivine dolerite
Dickson's Craigs		
Roxburgh and Forest ..	Ratho	Quartz dolerite
Lothians Quarry Co. ..	Edinburgh	Mugearite lava

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Water Supply.

Edinburgh and District.—The water supply of the City of Edinburgh is derived from three main sources, namely: (1) the Pentland Hills; (2) the Moorfoot Hills; (3) the Talla Water (one of the upper tributaries of the river Tweed).

Previous to the introduction of these supplies the inhabitants depended entirely on wells situated within the city. Authenticated accounts of the water supply to Edinburgh date as far back as 1621, when steps were taken for the introduction of the first gravitation supply. An Act was passed by the Scottish Parliament in that year for the introduction of water from the Comiston Springs, which rise about three miles to the south of Edinburgh, but it was not until 1681 that the water was actually brought into the city. The supply amounted to about 135,000 gallons per day, and was carried by a 3-in. lead pipe at a cost of about £3000.

About twenty years later additional springs were brought in from near the same source, and a lead pipe 4½ in. in diameter was substituted. No further addition to the supply was made until thirty-five years later, when after a time of great scarcity an additional volume was obtained from Bonally, six miles from Edinburgh, and other streams and springs on the north side of the Pentland Hills were brought by way of Swanston, and this supply was introduced in 1761. It was conveyed into the town by wooden pipes, which were mostly removed and iron pipes substituted in 1790.

Previous to the introduction of the Moorfoot water the whole of the supply was derived from the Pentlands.

The Edinburgh Water Company was formed in 1819, after the town had experienced a very great scarcity of water. The new Company at once applied to Parliament for powers to introduce the water of the Crawley Springs and part of the Logan Burn in the Glencorse Valley on the south side of the Pentland Hills. The water was introduced into Edinburgh in 1822, and the quantity amounted with the existing supplies to about 2,700,000 gallons per day. A reservoir was constructed in the Glencorse Valley in order partly to provide compensation to the burn, having regard to the numerous manufactories, chiefly paper-mills, on the North Esk, and partly to store water for the supply to Edinburgh.

In 1843 the Company introduced about 2,000,000 gallons per day of additional water from the Bavelaw, Listonshiels and Black Springs, which lie on the north side of the Pentlands. The manner of providing compensation in this case differed from that at Glencorse, and the same principle was adopted on subsequent occasions of a similar nature. Compensation reservoirs, calculated to contain a volume of water equal to eight months' yield of the springs, were constructed at Threipmuir and Harelaw, and having once been filled were handed over to the representatives of the mill-owners; all responsibility regarding them except as to their maintenance terminated as far as the Company were concerned; and the mill-owners have power to order the available water to be discharged in whatever daily quantities they consider best.

Another Act was obtained in 1847, which gave powers to construct four additional reservoirs and to increase the capacity of the Glencorse Reservoir by raising the water level 4 ft. The reservoirs constructed under this Act were Loganlee on the south side of the Pentlands and Clubbiedean, Torduff and Bonally on the north side of the chain. Clubbiedean and Torduff Reservoirs store the surplus water of the springs in winter for use during the dry months of summer.

In 1856 an Act was obtained authorising the introduction of the Colzium Springs, also rising on the northern slopes of the Pentland Hills towards the western extremity, and Harperrig Reservoir was constructed for the purpose of compensating the mill-owners on the Water of Leith. This reservoir was also handed over for the purposes of administration to the representatives of the mill-owners, as in the case of Threipmuir and Harelaw Reservoirs.

On account of the deterioration in the quality of the water left in the Water of Leith owing to the abstraction of the springs, the Act provided for a supply of pure spring water to the extent of about 400,000 gallons per day from the pipes of the Company to the various paper-makers and bleachers on the Water of Leith.

A still further supply was obtained from the Crosswood Springs, an Act for which was passed in 1863, and a reservoir was as usual constructed on the Crosswood Burn to compensate the mill-owners. The supply from the Pentland Works is so far peculiar as it consists almost entirely of spring water and does not require filtration. In dry years the supply from the Pentland Hills amounts to about 7,000,000 gallons per day.

In 1869 an Act was passed for taking over the works of the Water Company and investing them in a public Trust, consisting of representatives of Edinburgh, Leith and Portobello.

An application was immediately made to Parliament for power to introduce the water of St. Mary's Loch, but the Bill after passing the House of Commons was rejected by the House of Lords.

A year or two later the Trustees decided to adopt the Moorfoot or South Esk scheme, and the necessary Acts for this purpose were obtained in due course. The Moorfoot scheme consists of the utilisation of a drainage area amounting in all to about 14,500 acres. Three reservoirs were constructed, namely: (1) Gladhouse;

(2) Edgelaw ; (3) Rosebery. The supply to Edinburgh and District was drawn from Gladhouse Reservoir, the Edgelaw and Rosebery Reservoirs being used entirely for compensation purposes to the South Esk. A certain quantity was also obtained for Edinburgh from Portmore Loch, which was adapted for reservoir purposes by the construction of an embankment and outlet works. The water from Moorfoot is conducted to a service reservoir which was constructed at Alnwickhill near Liberton, and the water after being filtered there is distributed to the district.

The Moorfoot Works are capable of supplying Edinburgh with a daily quantity of 8,500,000 gallons in dry years.

About 1888, and for some years thereafter, the Trustees had under consideration the question of an additional supply of water, and decided in 1894 to adopt the Talla scheme. They obtained an Act in 1895 to introduce a supply from the Talla Water (one of the tributaries of the river Tweed near its source in Peeblesshire), and the Act authorising the works was passed the following year and the water was introduced in 1905.

In dry years the Talla Works as at present are capable of yielding practically 10,000,000 gallons per day for town consumption, and as the greater part of the aqueduct has been constructed sufficiently large to carry three times this quantity an increased supply may be obtained from adjoining tributaries of the Tweed at comparatively moderate cost.

The Pentland, Moorfoot and Talla Works are together capable of yielding at present 25½ million gallons per day, or sufficient to afford 40 gallons per head to a population of over 600,000. The population at present being supplied is 477,000, including, besides Edinburgh, Leith and Portobello, various small villages and burghs, such as Musselburgh, Dalkeith, Loanhead, Gilmerton, Liberton, Corstorphine, Colinton, Juniper Green, Currie and a few other places.*

The Upper Old Red Sandstone, as developed in the southern parts of the city and its southern suburbs, is the chief source of the permanently hard water which has proved so valuable for brewing purposes.

The strata crop out in a general way round the anticline of the Blackford Hill and dip to the north, north-west and north-east. They conduct the water beneath the overlying impervious rocks of the Cementstone group, which, together with the Calton and Colinton faults, act as dams impounding it beneath the greater part of the old town. The suburban railway has facilitated the transfer of certain of the town breweries to Duddingston, where the Craigmillar sandstones at the top of the Upper Old Red Sandstone furnish a copious supply. B. N. P.

The village of Lasswade obtains a supply of water from fluvio-glacial gravels on the north-west side of the Esk, a little below Melville Castle. Dalkeith is partially supplied by the Edinburgh and District Water Trust, and obtains an additional quantity from three bore-holes near Lugton Bridge, and from fluvio-glacial gravels near Elginhaugh and Viewfield. The wells in the last-mentioned

* We are indebted to Mr. R. Carstairs Reid, C.E., for this account of the water supply of Edinburgh and District.

locality are said to be 150 years old. Part of the village of Polton is provided with water procured from similar glacial gravels, which mantle both sides of the North Esk Valley in considerable thickness in that locality.

On a drift-covered area about two miles south-east of Rosewell a reservoir of considerable size has lately been made to collect water for the use of Roslin Asylum. A small natural stream flows into the reservoir and is impounded, but the overflow passes into a larger adjoining stream which was formerly fed directly by the small tributary.

Mining operations have often a deleterious influence on the springs and wells in their neighbourhood, as is well known. The pits near the centre of the Mid-Lothian Coal Basin, such as those of Eskbank and Olive Bank, collect, as might be expected, a special abundance of water, the pumping of which adds greatly to the working expenses. About 2600 gallons of water per minute was lately pumped from Olive Bank pit, and, during a recent visit, a feeder from one little crevice in the sandstone roof of an underground road was discharging 50 or 60 gallons per minute. This shaft top is slightly above the sea-level, and the depth is rather more than 600 ft., but all the water which comes into the lower part of the pit is fresh, while in the upper parts the water is rather salt.

In shallow pits it is found prudent to attend carefully to the surface drainage of the surrounding district, so that the rainfall may be carried off as quickly as possible, instead of finding its way downwards. A considerable part of the old bed of the Bilston Burn where it crosses the Edge Coal series has been covered with concrete, to prevent the water soaking down into the workings at a lower level.

Some of the water met with in the pits might be used in the surrounding districts. For steam and other purposes it would probably be suitable enough, but special precautions would be necessary before any could be used for domestic purposes, for much of the water encountered in mines, and also in coal-bearing strata elsewhere, is so charged with iron salts or with sulphates, etc., formed through the oxidation of iron pyrites, that it is unsuitable for domestic use. And for a similar reason, if bore-holes in search of drinking water were bored through rocks containing coal seams it would be necessary to tube portions of the holes so as to keep out deleterious affluents. In some feeders of water from the Coronation Seam, Newbattle Colliery, Newton Grange, the total sulphates amount to 130 grs. per gallon, in terms of sulphuric acid, nearly a third of which is combined with the iron in the water in the form of sulphate of iron, leaving 91·36 grs. of free sulphuric acid.*

It is probable that a supply of good water could be got by boring into the Roslin Sandstone series (Millstone Grit) in certain places near the centre of the Mid-Lothian Coal-field, for it is almost barren of coal seams, and in the New Mills day-level, east of Dalkeith, good feeders of water are met in the sandstones belonging to the series.

* Mr. M. Mackay, the manager of the colliery, states that this water rapidly corrodes the iron pipes in the workings exposed to its action, leaving behind a residue which consists to a large extent of some substance resembling graphite. The difficulty is overcome by diluting the Coronation water with other water derived from the Splint and Parrot workings.

Mining engineers have some dread of extending their workings to the Millstone Grit on account of its water-bearing capacity.

The Joppa Sandstone—the thick sandstone which is so often found above the Index (No. 4) Limestone—would also probably yield an abundant supply in many positions. In sinking the Lady Victoria shaft, Newbattle, this sandstone was found to be 14 fms. thick; the journal records that it yielded about 200 gallons of water a minute, and it is understood that a somewhat similar yield is still forthcoming.

St. Catherine's Balm Well, about three-quarters of a mile south of Liberton Church, yields some crude petroleum oil which floats on top of the water. It has been resorted to for centuries owing to its supposed curative properties and is still occasionally visited.* It appears to lie a very little south-east of the Pentland fault, and on the outcrop of the Oil-shale group, so that the presence of crude oil is not surprising. Mr. Martin, the manager of Niddrie Colliery, states that, some years ago, a runner of water containing a considerable proportion of crude oil was met with in making a deep drain nearly half a mile south-west of Niddrie House. The locality is only a little south-east of the supposed position of the Pentland fault, and probably on or near the crop of beds belonging to the Oil-shale group. It is well known that faults usually act as water barriers, the crushed shale often found along them being of a close impervious nature, so that the underground feeders which reach it from either side are intercepted and have to pass along the fault face, either laterally or upwards. Springs or stripes of wet ground are for this reason very often found along the course of faults in areas where the ground is almost free from drift. C. T. C.

St. Bernard's Well, near the Water of Leith, Stockbridge, Edinburgh, is also said to yield occasionally a very little crude petroleum. It is situated on the outcrop of the Wardie Shales, some of which are oil-producers (see p. 352), and it might, presumably, derive some crude oil from these beds. No trace of oil could, however, be observed in the water supplied for drinking purposes at a recent visit, nor is any mentioned in the analyses exhibited at the Pump Room. In general character the water is sulphurous, and allied in a character to some of the highly esteemed waters of Harrogate, Strathpeffer etc.

From a recent analysis executed by Dr. Falconer King† we learn that one gallon contains—

Total solid residue	55·20 grs.
Chlorine	3·90 „
Phosphoric acid	Distinct trace
Nitrates	None
Nitrites	None
Iron, lead, zinc	None
Saline ammonia	0·0021 grs.
Albuminoid ammonia	0·011 „
Lime	15·20 „
Magnesia	6·24 „
Sulphuric anhydride	11·12 „
Alkalies as soda	4·56 „
SH_2	0·043 cub. in.

* See D. Wilson's "Old Edinburgh," vol. ii. p. 235.
† "Scotsman," 29th June 1906.

It is also supposed that the lime, magnesia, sulphuric anhydride, alkalies as soda, and chlorine possibly exist in the following form:—

$CaCo_3$	26·14
$MgCo_3$	2·02
$CaSo_4$	0·95
$MgSo_4$	15·84
NaCl	6·43
$NaCo_3$	1·95

C. T C.

Western District.—The water supply of Bo'ness is piped from Lochcote Reservoir (2 miles S.S.W. of Linlithgow, Sheet 31), which gathers the springs and surface water draining from a portion of the hills lying to the west of it. Near the top of the hill on which the monument stands, about a mile and a half south of Bo'ness, Mr. Cadell has lately procured a limited supply of water by boring on the outcrop of the Wester Main Coal. The bore is a shallow one, only going down 21 ft. into the dolerite lying a little below the coal, and most of the water issues from the dolerite. The site of the bore is only about 25 ft. below the hilltop, and the adjoining strata show a considerable dip to the north-west, of perhaps 15° or 20°, but the dolerite makes a considerable outcrop on the slightly higher ground east of the bore, and the amount of rainfall on this crop is perhaps sufficient to account for the supply. An old well on lower ground, about 300 yds. south of the monument, is situated near the base of a thin band of sedimentary strata which intervenes between two other sheets of dolerite.

The town of Linlithgow is supplied with water from springs, and from a reservoir on the north side of Cocklerue. Shallow wells in the glacial sands on which the town stands yield supplies of water suitable for many purposes. The solid rocks, too, have been bored for water, but the supply thus obtained has been in some cases small, and of poor quality, presumably in consequence of the presence of igneous rocks.

A bore at the Mains Distillery (Sheet 31) found saline water which contained 140 grs. of sodium chloride per gallon.*

The Bathgate water supply is derived from borings, and the water is stored in the disused Petershill limestone quarry (Sheet 31), which has been converted into a reservoir. An increased supply might perhaps be obtained by deepening one of these bores so as to tap the West Kirkton Limestone—which might be expected between 300 and 400 ft. below the bottom of the Petershill Limestone.

C. T. C., E. B. B., G. W. G.

A considerable number of localities in the western portion of the area described are supplied with water obtained from Forrest Burn, near Forrestfield Station, eight miles west from Bathgate. Among these are Blackburn, Deans, Seafield, Breich, North Pumpherston, Broxburn and Uphall. The two last-mentioned towns have also an additional, older supply from Binny Reservoir, which is fed by the Binny Burn; the water is passed through filters above Uphall.

South Pumpherston and Mid Calder obtain water from springs on

* Explanation of Sheet 31, *Mem. Geol. Sur.*, p. 21; also *Proc. Roy. Soc. Edin.*, vol. ix. p. 367.

Corston Hill, on Lord Morton's property on the south side of Linhouse Water, three-quarters of a mile below Linhouse. The issue from the springs amounts to about 65,000 gallons per day, and, after being gathered into two concrete tanks, is conveyed away by a 3-in. pipe. The following is given as the analysis of the water :—

Total solids (grs. per gallon)	12·20
Chlorine (grs. per gallon)	8·80
Hardness (degree)	8·80
Free ammonia (parts per million)..	0·016
Albuminoid ammonia (parts per million)	0·008

Philpstoun and South Queensferry also obtain water from the west side of Corston Hill, but outside the area assigned to Morton Water Works above Morton, which were originally formed for the Kirkliston and Dalmeny districts, including South Queensferry. About 66,000 gallons per day are thus obtained for the South Queensferry district. An older supply to the last-mentioned town comes from two large reservoirs fed by the Ferry Burn, between Queensferry and Dalmeny, and from springs on the estate of Dundas, but this was found to be inadequate when the Forth Bridge began to be built and the training ship and guard ships of the Forth were anchored off the town.

Addiewell draws its supply from Cobbinshaw Reservoir, which was constructed as a compensation reservoir to yield water to the river Almond in lieu of that abstracted at Mid Calder for the use of the Glasgow and Edinburgh Canal.

Ratho, Kirknewton and Winchburgh districts obtain water partly from Selms Muir and partly from Ormiston.

Balerno is supplied with water from springs on Mansefield, a mile south of the village. J. S. G. W.

APPENDIX.

PART I. PALÆONTOLOGICAL.

Notes by G. W. Lee.

A. List of Localities for Carboniferous Fossils in Sheet 32, the east part of Sheet 31, and the northern margin of Sheet 24.

B. General List of Carboniferous Fossils arranged in their Systematic Order.

C. Lists of Post-Tertiary Fossils.

PART II. BIBLIOGRAPHICAL.

APPENDIX.

PART I. PALÆONTOLOGICAL.

The greater number of the fossils given in the following lists were gathered by the late Mr. J. Bennie, with some recent additions by Messrs. D. Tait and A. Macconochie. Many of the determinations are taken from lists in the published papers of Dr. R. H. Traquair, Dr. R. Kidston, and other authors, whose names are indicated by special signs (see p. 384).

The Survey specimens obtained in earlier years were named by Mr. R. Etheridge, jun., with the assistance of Messrs. H. B. Brady, T. Rupert Jones and J. W. Kirkby, who determined the Foraminifera and the Entomostraca. Most of the species quoted in the lists, however, were determined or re-named in the light of recent researches by the following specialists. Dr. R. H. Traquair has determined the Fishes; Dr. B. N. Peach, the higher Crustacea; Dr. R. Kidston, the Plants; and Dr. Wheelton Hind, the Lamellibranchs. Some of the Cephalopods have been examined by Dr. A. H. Foord. The determinations of the Brachiopods have been revised by Dr. C. B. Crampton and Dr. G. W. Lee, and the nomenclature of the Bryozoa and Gasteropods by Dr. Lee.

As the nomenclature of the Corals is now undergoing extensive revision, and as many specimens noted in the last edition of this memoir are not now accessible, it is not yet possible to furnish a representative list of these fossils; hence they have been omitted.

The lists have been prepared by Mr. D. Tait.

G. W. LEE.

NOTES ON THE DISTRIBUTION OF LIFE IN THE LOWER CARBONIFEROUS ROCKS (SHEET 32).

The Calciferous Sandstone series is sharply distinguished from the overlying Carboniferous Limestone by its Flora. This difference, pointed out by Dr. R. Kidston, F.R.S,* is well illustrated in the accompanying fossil-lists. Whether that distinction can be extended to the fauna of the two series is more open to question; a brief discussion on this point may here be attempted. The problem, so far as fish-life is concerned, has been recently investigated by Dr. R. H. Traquair, F.R.S.† He shows that the commonest species appearing in the Wardie Shales pass up into the Upper Limestone group, and that although some species are restricted to an horizon comprising the Borough Lee Ironstone and the South Parrot Coal Shale, the best course is to look upon the Lower

* *Proc. Roy. Phys. Soc. Edin.*, 1893, vol. xii. p. 219.

† "On the Distribution of Fossil-Fish Remains in the Carboniferous Rocks of the Edinburgh District," *Trans. Roy. Soc. Edin.*, 1903, vol. xl. p. 687.

Carboniferous rocks of the Central Valley of Scotland as forming one great life-zone so far as fishes are concerned, since the Borough Lee fish fauna is closely linked with that of the Dunnet Shale, and the latter again with those of the Burdiehouse Limestone and Wardie Shales.*

With regard to the Invertebrates, Dr. Vaughan's zonal system, which has given valuable results in England, is not applicable here in its entirety. The greater portion of the strata forming the Calciferous Sandstone series was evidently deposited under shallow water, and often estuarine conditions. Except at the top of the series representatives of a normal marine fauna of moderate depth are scarce and practically insufficient to secure a correct correlation with the zones established in England by means of Corals and hinged Brachiopods. An assemblage found in a calcareous zone in the Esk section, 50 yds. from the right bank of the river Esk and 150 yds. N. of Rogersrig Farm, $\frac{1}{4}$ mile N. E. of Carlops, is of great interest. The exact stratigraphical horizon of the beds cannot be fixed, although it must be low down in the series.

From this zone Messrs. Macconochie and M'Vey obtained a suite of fossils indicative of normal marine conditions, as testified by the presence of hinged Brachiopods, Bryozoa and Crinoid stems. Lamellibranchs, Gasteropods and Cephalopods are also represented, the former in great abundance.

The Brachiopods include *Productus*, Rhynchonellids and Athyrids. A large number of specimens of *Productus* were obtained; they all belong to the same species, and appear to be indistinguishable from *Productus burlingtonensis* Hall [Vaughan]. Owing to the mode of preservation the internal characters of the other Brachiopods could not be ascertained, but so far as external features can be trusted, the Rhynchonellids include a form allied to *Camarotoechia mitcheldeanensis* Vaughan, but apparently not identical with it. At first sight the apparently archaic character of the principal fossils suggested a Tournaisian age for the bed, but closer inspection having revealed the presence of a junciform *Lithostrotion*, together with the Brachiopods, there is thus conflicting evidence as regards the horizon. Since, however, *Lithostrotion* is a widely distributed genus not known from below the Visean, the best course is to place this bed in the Visean and to consider the *Productus* as a hardly modified descendant of *Pr. burlingtonensis*. It may also be that the *Productus* is but a homœomorph of *Pr. burlingtonensis*, but this point cannot be settled without the examination of specimens exhibiting characteristic internal features.

The marine beds of Clubbiedean Reservoir, Craiglockhart Quarry, Woodhall, Drumsheugh, etc., have yielded a fauna consisting mainly of Lamellibranchs, Gasteropods and Cephalopods. The Lamellibranchs belong to those forms which Dr. Hind considers characteristic of the Calciferous Sandstone series, but they cannot, at present, be used for defining narrow zones. The Gasteropods and Cephalopods are not characteristic enough at these localities to be of service in zoning.

As already stated, by far the greater portion of the Calciferous Sandstone series in Mid-Lothian does not contain a fauna permitting of zonal correlations with England. But in the Carboniferous Limestone series the rich assemblage of Invertebrates obtained from the Lower Limestones is the same as that characterising the D_2 zone of England. A glance at the fossil-lists will show that the Upper Limestones are not distinguished from the Lower Limestones by the presence of species peculiar to themselves, but rather by the absence of many of those species widespread in the Lower Limestones. It is hardly possible to establish a zone on this negative evidence, especially since there is nothing to show why the unrepresented forms have disappeared. It is, however, possible that by adopting more sharply defined specific appellations, many

* *Loc. cit.* p. 701.

of the species tabulated in the present lists might be restricted to narrower limits.

In the strata immediately succeeding the topmost limestone, that is to say, at the base of the Millstone Grit, a highly individual facies is exhibited by the invertebrate fauna. The interesting character of the Lamellibranch fauna was pointed out a few years ago by Dr. Wheelton Hind,* and the results of his examination of materials from various parts of Scotland are embodied in a recent memoir.†

Dr. Hind has detected a point of great importance that quite 50 per cent. of the Lamellibranchs are species originally described from the Coal Measures of Nebraska and Illinois in North America. He has also remarked that the Gasteropods show a strong relation to this North American fauna, and that the Brachiopod fauna indicates a late period of Carboniferous time. Further study based on materials collected since Dr. Hind's memoir was written enables us to make a more decided statement as regards the Brachiopods. In Sheet 32 a bed situated 27 to 30 ft. above the Castlecary Limestone, in the Bilston Burn section (locality 110*a* of fossil-list), besides yielding representatives of Lamellibranchs and Gasteropods of American facies, contains the following forms of Brachiopods. The Rhynchonellids are represented by two species, one of which is closely allied to *Pugnax pugnus* (Martin), while the other seems to be new to Britain; the Athyrids are represented by *Seminula subtilita* (Hall), or a form nearly allied to it; of the Orthotetids, *Derbya? kelli* (M'Coy) is possibly present, and the species of *Productus* are referable to *P. margaritaceus* Phillips, and to a distinct mutation of *P. semireticulatus* (Martin). In other districts beds situated on the same horizon have likewise yielded an interesting fauna. From the fossils collected at Garngad Road, Glasgow, by Mr. J. Neilson, Davidson figured *Productus carbonarius* de Koninck, and under the name *Streptorhynchus crenistria* var. *cylindrica* M'Coy he figured a shell allied to *Meekella* (*Orthotetina*). To these may be added a coarse-ribbed mutation of *Productus muricatus* Phillips, and a form bearing a strong resemblance to *P. cora* d'Orb. [the American and Russian form].

Productus cora, *P. carbonarius* and the genus *Meekella* seem everywhere restricted to the Upper Carboniferous. Except *Pugnax pugnus* the other Brachiopods are new to Scotland, and as already mentioned Dr. Hind finds that 50 per cent. of the Lamellibranchs are American Coal-Measures species. The occurrence of so many foreign species through migration seems unlikely since in America and Russia they occur at an horizon which is apparently higher in the sequence. Moreover, a number of them are likely to have already existed in Carboniferous Limestone time. A *Meekella* (*Orthotetina*) occurs in the Upper Limestone group of Ayrshire, and recently (March 1909) Dr. Hind recognised the presence of *Prothyris elegans* Meek and *Protoschizodus curtus* (M. & W.) in the cores of a bore put down near Stirling. The position of the bed from which these fossils have been obtained is probably not higher up than the Index Limestone position. It is interesting to note that in this Stirling bore the bed that yielded these species is a black shale not unlike the shale which, at the base of the Millstone Grit, contains *Prothyris elegans* at nearly all the localities where it was found. It seems highly probable that many of these American species were dependent for their development on definite physical conditions, which occurred only at a few localities during Upper Limestone time, but were more prevalent at the base of the Millstone Grit. On the

* "Summary of Progress," *Mem. Geol. Sur.* for 1905, p. 147.

† Wheelton Hind: "On the Lamellibranch and Gasteropod Fauna found in the Millstone Grit of Scotland," *Trans. Roy. Soc. Edin.*, 1908, vol. xlvi. p. 331.

other hand, it is significant that similar black shales form a conspicuous feature of the Lower Limestone group, especially about the position of the top "Hosie" limestone, yet they have so far not yielded any representatives of this fauna of American facies. In the event of the latter being found at a number of localities in the Upper Limestones, then their occurrence, coupled with the absence of many of the forms common in the Lower Limestones, could perhaps be used in Central Scotland to define a zone comprising the Upper Limestones. G. W. LEE.

A. LIST OF LOCALITIES FOR CARBONIFEROUS FOSSILS IN SHEET 32, THE EAST PART OF SHEET 31, AND THE NORTHERN MARGIN OF SHEET 24.

1. Charlestown Limestone Quarries, 4 miles W. of Inverkeithing. Lower Limestones.

1*a*. Charlestown Shore between tide-marks, 170 yds. S.W. of Charlestown railway station and 330 yds. E. of Charlestown Harbour. Shale between the four-foot limestone and the coal below. Lower Limestones.

2. Rosyth Shore, near high-water mark in the first bay E. of the ruins of Rosyth Church [=from 200–500 yds. E. of it]. Calciferous Sandstone.

2*a*. Rosyth Shore, *Naiadites* Limestone, between tide-marks, ¼ mile S. of Rosyth Farm and ⅓ mile W.N.W. of Rosyth Castle. Calciferous Sandstone.

3. Rosyth Shore, at high-water mark, on seaward side of wall at old limestone quarry in field ¼ mile W. of Rosyth Farm, on north side of fault. Shale between the four-foot crinoidal limestone and the coal which underlies it. Lower Limestones.

3*a*. Inverkeithing, 1½ miles N.E. of, and ¾ mile N.W. of Donibristle, west side of railway cutting, at the bend, calcareous shale and nodules 10 ft. above an oil-shale [Cephalopod Bed]. Calciferous Sandstone.

4. Port Haven, ½ mile S.W. of Aberdour. Calciferous Sandstone.

5. Inchkeith, Island of, Firth of Forth. Calciferous Sandstone.

6. Bo'ness Station, ½ mile S.E. of, Chance Pit [No. 21 Kinneil]. Roof of Smithy Coal. Edge Coals. Sheet 31.

7. Bo'ness Station, ½ mile S. of, No. 18 Pit Kinneil. Roof of Smithy Coal. Edge Coals. Sheet 31.

7*a*. Bo'ness Station, nearly 1½ miles S.E. of, No. 6 Pit Kinneil. Above Red Coal. Edge Coals.

8. Bo'ness, at Grange. Roof of East Main Coal. Edge Coals.

8*a*. Bo'ness, bing of No. 9 Pit, about 1000 ft. N. of Bonhard House. Shale above Lower Ironstone and Parrot Coal. Edge Coals.

9. Bo'ness, 2 miles S.E. of, Cowsie Mine. Lower Ironstone of Bo'ness. Edge Coals.

10. Bo'ness, 2 miles S.E. of, Duncan Shale Pit, shale immediately above ironstone of coal-field. Edge Coals.

11. Cauldhame Old Quarry, 1¼ miles S.E. of Linlithgow. Lower Limestones.

13. Hillhouse Quarries, 1½ miles S. of Linlithgow. Lower Limestones.

14. Whitebaulks Quarry, 1½ miles S.S.E. of Linlithgow. Lower Limestones.

15. Tartraven Old Quarry, 4 miles S. of Linlithgow. Lower Limestones.

16. Baadsmill, limestone exposed on left bank of Harwood Burn S. of Addiewell and 1¼ miles N.W. of Cobbinshaw Reservoir. Lower Limestones.

17. Cobbinshaw Reservoir, limestone pit at its S.W. end. Lower Limestones.

17*a*. City of Edinburgh, pipe track in Fountainbridge. Calciferous Sandstone.

18. City of Edinburgh, excavation for foundation of Scotsman Newspaper Office, North Bridge Street. Calciferous Sandstone.

18*a*. City of Edinburgh, drain cutting, High Street, near Tron Church. Calciferous Sandstone.

19. Holyrood Palace, drain cutting in Holyrood Park, near S.E. corner of palace wall. Calciferous Sandstone.
20. Camstone Quarry, Salisbury Crags. Calciferous Sandstone.
20*a*. Limestone on track between St. Anthony's Well and St. Anthony's Chapel. Calciferous Sandstone.
21. St. Anthony's Chapel, tuff in cliff below—Holyrood Park. Calciferous Sandstone.
22. Lochend Loch, E. margin, 1¼ miles N.E. of Register House, Edinburgh. Calciferous Sandstone.
23. Drumsheugh, Water of Leith, City of Edinburgh. Calciferous Sandstone.
24. Dean Bridge, Water of Leith, City of Edinburgh. Calciferous Sandstone.
25. Craiglockhart Hill Quarry, north side of Colinton Road. Calciferous Sandstone.
26. Suburban Railway Cutting, north side of Canal, south-west side of Edinburgh. Calciferous Sandstone.
27. Craigleith Quarry, west side of the City of Edinburgh, from the shales overlying the sandstone. Calciferous Sandstone.
28. Craigleith Quarry, from the sandstone. Calciferous Sandstone.
29. Barnton Old Pavement Quarry, under whin sill, north side of Corstorphine Hill. Calciferous Sandstone.
30. Wardie Shore, between Trinity and east side of Granton Harbour. Calciferous Sandstone.
31. Granton Harbour, shore between western breakwater and pier. Calciferous Sandstone.
32. Granton, shore W. of the harbour, below battery. Calciferous Sandstone.
33. Granton, sea quarry, south side. Calciferous Sandstone.
34. Granton, shore W. of quarry, under Muirhouse. Calciferous Sandstone.
35. Granton, shore W. of harbour, at telegraph cable. Calciferous Sandstone.
36. Cramond Shore, W. of mouth of river Almond, and W. of Eagle Rock. Calciferous Sandstone.
37. Almond River, ½ mile W. of Cramond Bridge, close to under side of whin sill. Calciferous Sandstone.
38. Dalmeny Shore, between Longcraigs Pier and Forth Bridge. Calciferous Sandstone.
39. Dalmeny Railway Cutting, N. of Wester Dalmeny Farmhouse. Calciferous Sandstone.
41. Hopetoun Shore, E. of Society, and 2 miles W. of Forth Bridge. Calciferous Sandstone.
42. Hopetoun Shore, N. of Abercorn, in little bay E. of point. Calciferous Sandstone.
43. Midhope Burn, 100 yds. below sawmill, near Abercorn, 4 miles W. of Forth Bridge. Calciferous Sandstone.
44. Hailes Quarry, near Kingsknowe Railway Station, 4 miles S.W. of Edinburgh. Calciferous Sandstone.
45. Redhall Quarry, near Kingsknowe Railway Station. Calciferous Sandstone.
46. Water of Leith, right bank near Slateford, under aqueduct. Calciferous Sandstone.
47. Water of Leith, right bank near Slateford, S. of Canal Bridge. Calciferous Sandstone.
48. Water of Leith, opposite Boag's Mill, under Redhall House, 3½ miles S.W. of Edinburgh. Calciferous Sandstone.

49. Water of Leith, left bank, midway between Boag's Mill and Kates Mill, under Redhall Quarry. Calciferous Sandstone.
50. Water of Leith, railway cutting on left bank, midway between Boag's Mill and Kates Mill, 4 miles S.W. of Edinburgh. Calciferous Sandstone.
51. Water of Leith, railway cutting, opposite Kates Mill, midway between Slateford and Colinton. Calciferous Sandstone.
52. Water of Leith, stream course, opposite Kates Mill. Calciferous Sandstone.
53. Water of Leith, stream course, a little above Kates Mill. Calciferous Sandstone.
54. Water of Leith, railway cutting, opposite Redhall Mill, about 4 miles S.W. of Edinburgh. Calciferous Sandstone.
55. Water of Leith, stream course, at Redhall Mill and a few yards above it. Calciferous Sandstone.
56. Water of Leith, beneath dam of Redhall Mill. Calciferous Sandstone.
57. Colinton, railway tunnel at, 4 miles S.W. of Edinburgh. Calciferous Sandstone.
58. Water of Leith, immediately above Colinton. Calciferous Sandstone.
59. Water of Leith, left bank, above Spylaw House. [*Schizodus* Limestone.] Calciferous Sandstone.
60. Water of Leith, beneath dam, above West Mill, Colinton. Calciferous Sandstone.
61. Woodhall, Water of Leith, right bank at ford below weir, near Juniper Green, 5 miles S.W. of Edinburgh. Calciferous Sandstone.
62. Juniper Green, Water of Leith. Calciferous Sandstone.
63. Clubbiedean Reservoir, south side, 1½ miles E.S.E. of Currie and about 6 miles S.W. of Edinburgh. Calciferous Sandstone.
64. Raw Camps Limestone Quarry, E. of Mid-Calder, 10 miles S.W. of Edinburgh. Calciferous Sandstone.
65. River Almond opposite Illieston, 2½ miles N.E. of Mid-Calder. Calciferous Sandstone.
66. River Almond opposite Clappertonhall, 1½ miles N.E. of Mid-Calder. Calciferous Sandstone.
67. Mid-Calder, sandstone quarry on left bank of Linhouse Water, opposite Oakbank Oil Works. Calciferous Sandstone.
67*a*. Mid-Calder, sandstone quarry on right bank of Linhouse Water, below Oakbank Oil Works. Calciferous Sandstone.
68. Mid-Calder, left bank of Linhouse Water, above Carstairs Railway Bridge. Calciferous Sandstone.
69. Mid-Calder, Linhouse Water, above and below felstone dyke, between Calder Hall and Calder Wood. Calciferous Sandstone.
70. Mid-Calder, from tunnel between Calder Hall and Calder Wood. Calciferous Sandstone.
71. Murieston Old Limestone Quarry, 2½ miles S.W. of Mid Calder. Calciferous Sandstone.
72. Murieston Water, ¼ mile S. of Skivo, above felstone, ¾ mile S.S.E. of Newpark Railway Station. Calciferous Sandstone.
73. Murieston Water, near Harburn, left bank 140 yds. up from road bridge, and down stream from Coalheugh. Calciferous Sandstone.
74. West Calder, near the Chemical Works. Calciferous Sandstone.
75. West Calder, Harwood Burn, above Hermand Oil Works.
76. West Calder, at Hermand Oil Works. Calciferous Sandstone.
77. West Calder, 1¼ miles N.E. of, Harwood Burn under bridge to Limefield House and opposite old mill. Calciferous Sandstone.

78. West Calder, Harwood Burn, left bank below double bridge under Limefield House. Calciferous Sandstone.
79. West Calder, Harwood Burn, right bank, 300 yds. below [under Limefield House] double bridge. Calciferous Sandstone.
80. Pumpherston Oil-Shale Works, between Broxburn and Mid Calder. No. 1 or Roman Camp Pit at north end of outcrop of Pumpherston Shale. Calciferous Sandstone.
81. Broxburn, Kirkhill, shale at old pit. Calciferous Sandstone.
82. Blackburn, E. of, and 2 miles N.W. of West Calder. Seafield or Houston Coal. Calciferous Sandstone.
83. Niddry Burn, 200 yds. above Ecclesmachan. Calciferous Sandstone.
84. Deans, No. 2 Pit [Dunnet Shale], ¾ mile W. of Livingston Railway Station, and 3 miles E. of Bathgate. Calciferous Sandstone.
85. Deans, No. 1 Pit, ¾ mile W. of Livingston Railway Station, and 3 miles E. of Bathgate. Calciferous Sandstone.
86. Ladysmith Oil-Shale Pit bing, ¾ mile W. of Livingston Railway Station, and 3 miles E. of Bathgate. Calciferous Sandstone.
86*a*. Livingston village, stream ¼ mile S.W. of, at Charlesfield. Calciferous Sandstone.
87. Straiton Oil Works, near Burdiehouse, 4½ miles S.S.E. of Edinburgh. Calciferous Sandstone.
89. Burdiehouse Limestone Quarry, 4½ miles S.S.E. of Edinburgh. Calciferous Sandstone.
90. Niddrie, 3 miles E. of Edinburgh. Bing of Nos. 10 and 11 Pits. Edge Coals.
91. Niddrie, near, in north bank of the more northerly of the two railway cuttings, about ½ mile W. of New Craighall, and 6 yds. E. of the locomotive water hydrant. Limestone between Nos. 5 and 6 Limestones. Upper Limestones.
91*a*. Niddrie, near, as above, coal half-way between Nos. 5 and 6 Limestones. Upper Limestones.
91*b*. Niddrie, near, as above, 60 ft. above No. 6 Limestone. Lower third of Millstone Grit.
92. Niddrie, near, blackband ironstone and shale near horizon of North Coal. Edge Coals.
93. Niddrie, near, pit working South Parrot Coal [between Nos. 4 and 5 Limestones], shale on top of South Parrot Coal. Upper Limestones.
94. Niddrie, near, shale associated with the Four-Foot Coal. Lower Coal Measures.
95. Niddrie, near, Klondyke or New Craighall Pit. *Carbonicola* bed above the Fifteen-Foot Coal. Lower Coal Measures.
96. Victoria Old Coal Pit, 590 yds. S.W. of Stonybank, 1 mile S.W. of Musselburgh. Lower Coal Measures.
97. Loanhead, 5 miles S. of Edinburgh. Loanhead Ironstone No. 1. Middle of Edge Coals.
98. Loanhead. Boroughlee Ironstone, or Loanhead Ironstone No. 2. Near top of Edge Coals.
99. Gilmerton Limestone Quarry, 4 miles S.E. of Edinburgh. Lower Limestones.
100. Gilmerton, Ferniehill Old Limestone Quarry. Lower Limestones.
101. Gilmerton, Venturefair Pit, Gilmerton Ironstone, between Nos. 1 and 2 Limestones. Lower Limestones.
102. Gilmerton, railway cutting, ½ mile S.E. of village and 58 yds. N.E. of road bridge, Extra Limestone between Nos. 4 and 5 Limestones. Upper Limestones.

103. Woolmet, new pit sinking, 1¼ miles S.E. of Niddrie House and 1½ miles N.E. of Gilmerton. Lower Coal Measures.
104. Bilston Burn, 1 mile S.W. of Loanhead, at Dryden, shale below Gilmerton Limestone. Lower Limestones.
105. Bilston Burn, 1 mile S.W. of Loanhead, at Dryden, shale below North Greens Limestone. Lower Limestones.
106. Bilston Burn, left bank below Pathhead farmhouse, shale in middle of Bilston Burn Limestone. Lower Limestones.
106*a*. Bilston Burn, a few feet above Bilston Burn Limestone. Lower Limestones.
107. Bilston Burn, at junction with Dryden Burn. Upper Limestones.
107*a*. Bilston Burn, a few feet up stream from junction with Dryden Burn. Upper Limestones.
108. Bilston Burn, near Polton, 100 to 150 yds. up stream from the old stone bridge. Beds between Nos. 5 and 6 Limestones. Upper Limestones.
109. Bilston Burn, on lower side of old stone bridge, near Polton; beds 30 to 40 ft. below the No. 6 Limestone. Upper Limestones.
110. Bilston Burn, above No. 6 Limestone, where stream runs along the strike—shale overlying a thin coal. Lower third of Millstone Grit.
110*a*. Bilston Burn, 27 to 30 ft. above No. 6 Limestone. Lower third of Millstone Grit.
111. Bilston Burn, ¼ mile W. of Polton Railway Station, right bank nearly opposite conduit under road—impure coal. Lower third of Millstone Grit.
111*a*. Broomieknowe Railway Cutting, 7 miles S.E. of Edinburgh, east end of station platform—in bottom of Splint Coal. Lower Coal Measures.
111*b*. Broomieknowe Railway Cutting, east side of station house—top of first coal below the Splint Coal. Lower Coal Measures.
112. Broomieknowe Railway Station. Shale above the Parrot Rough Coal exposed at the steps on west side of the station house. Lower Coal Measures.
112*a*. Broomieknowe Railway Cutting, between the station and the bridge —Jewel Coal. Lower Coal Measures.
113. Broomieknowe Railway Cutting, west side of road bridge and at the east end of the railway tunnel—impure coal 100 to 120 ft. below Jewel Coal. Lower Coal Measures.
114. Polton Colliery, Eldendean Pit, from roof of Parrot Rough Coal. Lower Coal Measures.
115. Polton Colliery, No. 3 Pit. Pavement of Rough Coal. Lower Coal Measures.
116. Polton Colliery, pit presently working ½ mile S. of Bonnyrigg. Roof of Parrot Rough Coal. Lower Coal Measures.
117. Bonnyrigg, Viewfield Sandstone Quarry. Lower Coal Measures.
117*a*. Lasswade, ¼ mile N. of, on right bank of river North Esk. Upper two-thirds of Millstone Grit.
118. Roslin Gunpowder Mills, south end, right bank of river North Esk, opposite No. 4 house, at base of cliff immediately below the branch stream which enters from the E. and also just below the bridge. Lower third of Millstone Grit.
119. Roslin Gunpowder Mills, south end, left bank, North Esk River, upper side of bridge. Impure coal. Lower third of Millstone Grit.
120. Roslin Gunpowder Mills, upper side of road on west side of glen, behind No. 25 house. Lower third of Millstone Grit.

122. Roslin, small stream that enters the Esk from the E., a little N. of Roslin Castle—between two waterfalls. Base of Lower Coal Measures.
123. Between Polton and Roslin, near middle of E. and W. flowing portion of river less than ¼ mile S. of Glenesk House, Polton. Upper two-thirds of Millstone Grit.
124. Between Polton and Roslin, east bank of river North Esk about ¼ mile S. of Springfield House, at sharp bend of river a little down stream from the summer-house perched on the edge of the cliff—band about 40 ft. above river bed. Upper two-thirds of Millstone Grit.
124*a*. Polton, left bank, river North Esk, ⅛ mile above its junction with Bilston Burn. Upper two-thirds of Millstone Grit.
125. Whitehill Colliery, Rosewell, ½ mile S. of Hawthornden Railway Station. Lower Coal Measures.
126. Auchindinny, 2 miles N.E. of Penicuik, left bank of river North Esk ¼ mile due E. of Easter Auchindinny Bridge, escarpment a few yards W. of where the little stream enters from the N. Lower third of Millstone Grit.
127. Auchindinny, left bank of river North Esk, where beds are vertical and bent; at curve of river at nearest point to south wall of Glencorse Barracks. Lower third of Millstone Grit.
128. Glencorse Barracks, 1½ miles N.E. of Penicuik. In the stream that flows eastwards into the North Esk—S. of the Barracks and on north side of Beeslack. At point 20 to 30 yds. from junction with North Esk, a few feet above the coal. Lower third of Millstone Grit.
129. Glencorse Barracks, stream S. of, midway between river North Esk and the public road to the N.W., a small exposure on right bank, is probably sometimes covered. Upper two-thirds of Millstone Grit.
130. Glencorse Barracks, stream S. of, about 60 yds. S.E. of the public road. Beds forming a small scarp on right bank. From light-coloured sandy ironstone on top of bank and in bed of stream farther down round the bend. Upper two-thirds of Millstone Grit.
131. Auchindinny, in stream about midway between Auchindinny House and Kirkettle Farm and ¼ mile S.E. of Firth House. Upper Limestones.
132. Auchindinny, fully ¼ mile N.E. of Maybank, 60 to 80 yds. up the main stream from the branch—beds below the coal. Lower third of Millstone Grit.
133. Auchindinny, at junction of two streams fully ¼ mile N.E. of Maybank. Lower third of Millstone Grit.
134. Auchindinny, 100 to 150 yds. below junction of two streams fully ¼ mile N.E. of Maybank—bed above the coal and at base of massive yellow sandstone. Lower third of Millstone Grit.
135. Auchindinny, small branch stream S. of Auchindinny House, 20 to 30 yds. from junction with main stream—beds under the coal. Lower third of Millstone Grit.
136. Auchindinny, as before, about midway between bend of stream and wood — E. of Maybank. Lower third of Millstone Grit.
137. Penicuik, Mauricewood Coal Pit. Upper Limestones.
138. Penicuik, ½ mile N.E. of, North Esk River—sandstone overlying No. 6 Limestone. Lower third of Millstone Grit.
139. Penicuik, North Esk River, left bank, near Valleyfield Paper Mills—shale below No. 5 Limestone. Upper Limestones.

140. Penicuik, 100 to 200 yds. up stream from Penicuik Bridge. Lower Coal Measures.
141. Black Burn, right bank below Halls, 1 mile S. of Penicuik—shale below No. 4 Limestone. Upper Limestones.
142. Hebershaw House, Old Quarry S.E. of, near Howgate, 2 miles S.E. of Penicuik—shale above No. 1 or No. 2 Limestone. Lower Limestones.
143. Lillyburn Sandstone Quarry, 2 miles E.S.E. of Penicuik. Edge Coals.
144. Mount Lothian Old Limestone Quarries, 3 miles S.E. of Penicuik. No. 2 Limestone. Lower Limestones.
145. Fullarton Limestone Quarries, 3½ miles S.E. of Penicuik. No. 2 Limestone. Lower Limestones.
146. Hare Burn, 1½ miles S.W. of Penicuik Railway Station, 40 yds. S.W. of fence and nearly ½ mile S.W. of bridge where burn crosses to S.E. side of road. Lower Coal Measures.
147. Hare Burn, 1½ miles S.W. of Penicuik, 100 to 150 yds. W. of the east margin of Hurly Wood. Ferruginous sandstone. Upper Limestones.
147*a*. Hare Burn, 70 to 80 yds. W. of the east margin of Hurly Wood. Ironstone. Upper Limestones.
148. Brunston Castle and Auchencorth, midway between. On W. bank of North Esk River [Coral Bed = No. 5 Limestone]. Upper Limestones.
149. Monks Burn, about 4 miles S.W. of Penicuik, right bank opposite Unthank. Lower Limestones.
150. North Esk River [Habbie's Howe], left bank below Peggy's Pool. Shale below and associated with No. 2 Limestone. Lower Limestones.
151. Brunston Colliery, 3 miles S.W. of Penicuik. No. 2 Limestone. Lower Limestones.
152. Brunston Colliery, 3 miles S.W. of Penicuik. Shale between Nos. 1 and 2 Limestones. Lower Limestones.
153. Cornton Burn, 2 miles S.W. of Penicuik, left bank opposite Cornton. Upper Limestones.
154. Cornton Burn, right bank opposite Cornton, *Productus* bed above black shale. Upper Limestones.
155. Cornton Burn, black shale below No. 4 Limestone. Upper Limestone series.
156. Braidwood Burn, S.W. of Penicuik, right bank above Matthew's Linn. Shale above No. 2 Limestone. Lower Limestones.
157. Carlops Limestone Quarry, 4½ miles S.W. of Penicuik. Sheet 24. Lower Limestones.
157*a*. Carlops, River North Esk, in old river bank 30 yds. W. of the stream and 150 yds. N. of Rogersrig Farm. Calciferous Sandstone.
157*b*. Carlops, River North Esk. Limestone underlying the bed of lava, [Burdiehouse Limestone]. Calciferous Sandstone.
157*c*. Carlops, River North Esk, right bank, No. 2 Oil-Shale in ascending order. Calciferous Sandstone.
157*d*. Carlops, River North Esk, at junction with Amazondean Burn. Soft calcareous shale underlying an oil-shale. Calciferous Sandstone.
158. Kittly Bridge, Carlops, right bank of river Esk. Shale above limestone. Lower Limestones. Sheet 24.
158*a*. Kittly Bridge, above, on bank of small stream on right bank of North Esk. Black shale below No. 1 Limestone. Lower Limestones. Sheet 24.

159. Deep Syke, near Whitefield, Macbiehill. White crystalline limestone from Talla water tunnel at point near here. Lower Limestones. Sheet 24.
160. Whitefield Limestone Quarries, between Carlops and Macbiehill Railway Station. Lower Limestones. Sheet 24.
161. Whitefield Talla water pipe track, near Upper Whitefield. Lower Limestones. Sheet 24.
162. Cairn Burn, Harlaw Muir, ¼ mile N.E. of road to Carlops. Lower Limestones.
163. Bents Quarries, ¼ mile S. of Macbiehill Railway Station. Lower Limestones. Sheet 24.
164. Whim Old Limestone Quarries, midway between Leadburn and Macbiehill Railway Stations. Lower Limestones. Sheet 24.
165. Hillhead Quarry, near Cockmuir Bridge. Shale above No. 1 Limestone. Lower Limestones. Sheet 24.
166. Side Quarries, 4½ miles E.S.E. of Penicuik. Lower Limestones. Sheet 24.
167. Esperston Limestone Quarries, 6½ miles S. of Dalkeith. Lower Limestones.
168. Middleton Limestone Quarries, 6½ miles S.S.E. of Dalkeith. Lower Limestones.
169. Arniston, near Gorebridge, ¼ mile W. of Arniston House, right bank of river South Esk on lower side of bridge ¾ mile S. of Carrington. Edge Coals.
170. Arniston, ¼ mile W. of Arniston House, left bank, river South Esk, 200 yds. down stream from the bridge which is S. of Carrington.
171. Arniston, left bank of river South Esk, a little farther up than midway between the stream entering from the S. and the bend to the W., between Carrington and Arniston Mains. Upper two-thirds of Millstone Grit.
172. Arniston Glen, in the steep slope on left bank 100 to 150 ft. above the stream, at bend about 50 yds. up stream from the wooden footbridge — down stream from preceding locality. (Marine Bed.) Lower third of Millstone Grit.
173. Arniston Glen, ¼ mile N.W. of Arniston Mains, about 150 yds. up stream from footbridge—beds under the Marine Bed. Lower third of Millstone Grit.
174. Arniston Glen, ¼ mile N.W. of Arniston Mains, about 50 yds. up stream from footbridge. Thin coal and sandstone overlying it. Lower third of Millstone Grit.
175. Arniston Glen, ⅛ mile S. of the old stone bridge which is W. of Shank—left bank near top of big sandstone cliff. Lower third of Millstone Grit.
176. Arniston Glen, ⅙ mile S. of the old stone bridge which is W. of Shank—band overlying thin coal and fireclay. Lower third of Millstone Grit.
177. Arniston Glen, left bank, 1 mile W.S.W. of Gorebridge and ½ mile W.S.W. of Arniston Bridge, at sharp bend of stream W. of, and down stream from, the old stone bridge W. of Shank. Upper two-thirds of Millstone Grit.
178. Arniston Glen, ½ mile N.W. of Arniston Bridge, about ¼ mile S.S.E. of Kirkhill—up stream round the sharp bend above the water-wheel. Marine nodular limestone. Lower third of Millstone Grit.
179. Arniston Glen, as before, farther down stream at the sharp bend at the water-wheel. Lower third of Millstone Grit.

180. Arniston Glen, 1 mile N.W. of Gorebridge, near sharp bend of river, S. of Kirkhill and W. of road bridge across the Esk. Upper two-thirds of Millstone Grit.

180*a*. Gorebridge, a few yards up from the bridge over the Gore Water. No. 4 Limestone and Shale. Upper Limestones.

181. Arniston Colliery, Camp Pit, S.E. of Blinkbonny Quarry, top of Parrot Coal. Edge Coals.

182. Arniston Colliery, Emily Pit, top of Parrot Coal. Edge Coals.

183. Arniston Colliery, Engine Pit, roof of Kailblades Coal. Edge Coals.

184. Blinkbonny Quarry, 1 mile N.N.E. of Gorebridge. No. 3 Limestone. Lower Limestones.

185. Newbattle Colliery, Lady Victoria and Lingerwood Pits, top of Parrot Coal. Edge Coals.

186. Newbattle Colliery, Easthouses Pit, top of Parrot Coal. Edge Coals.

187. Newbattle Colliery, Bryans Pit, roof of Kailblades Coal. Edge Coals.

188. Prestonholm, about ½ mile S. of Dalhousie Castle, river South Esk, left bank, at small sandstone quarry S.W. of two cottages on opposite bank. Upper two-thirds of Millstone Grit.

189. Dalhousie Castle, ½ mile N.N.E. of, in Murder Dean old sandstone quarry on right bank of river South Esk, fully 1 mile S.S.E. of Eskbank. Upper two-thirds of Millstone Grit.

190. Dalkeith, river South Esk, left bank, S.W. of Newmills Bridge and W. of Brewlands. Lower Coal Measures.

191. Eskbank, river North Esk, up stream from Elgin Haugh and down stream from weir—shale above Parrot Rough Coal. Lower Coal Measures.

192. Eskbank, as above, shale above the coal that overlies the Parrot Rough Coal. Lower Coal Measures.

193. Eskbank Coal Pit, ¼ mile N. of Railway Station. Lower Coal Measures.

194. Dalkeith Palace Grounds, right bank, river North Esk, at bend a little less than ⅙ mile S.W. of junction with river South Esk, E. of Sheriffhall Mains. Top beds of Lower Coal Measures.

195. Dalkeith Palace Grounds, right bank, river South Esk, at the sharp bend N.E. side of Cat Haugh, ½ mile N.E. of the Palace. Middle Coal Measures (?).

195*a*. Dalkeith Palace Grounds, E. bank of river South Esk, 200 yds. above its junction with North Esk. Lower Coal Measures.

196. Dalkeith Palace Grounds, left bank, river Esk, ⅙ mile S.W. of Smeaton Bridge. Lower Coal Measures.

197. Dalkeith Palace Grounds, Smeaton Burn, 170 yds. N.N.E. of Lodge. Lower Coal Measures.

198. Smeaton Burn, 2 miles N.N.E. of Dalkeith—shale above 8-inch coal on both sides of burn, 50 yds. E. of road. Lower Coal Measures.

199. Smeaton Burn, 100 to 200 yds. S. of Smeaton House, 2 miles N.N.E. of Dalkeith. Lower Coal Measures.

199*a*. Smeaton Dean, ¼ mile N.E. of Smeaton Railway Station. Shale heap at old working 50 yds. W. of old road bridge. Lower Coal Measures.

199*b*. Smeaton Shaw Railway Cutting. Millstone Grit.

200. Smeaton Old Coal Pit, 1 mile N.E. of Dalkeith. Lower Coal Measures.

201. Balaclava Old Pit, Shawfair Farm, 2 miles N.N.E. of Dalkeith. Lower Coal Measures.

203. Joppa Sandstone Quarry—shale overlying No. 4 Limestone. Upper Limestones.
204. Joppa Shore, between tide-marks, about 43 yds. W. of the westmost corner formed by wall of salt pans—impure coal 2 to 3 in. thick—below the lowest nodular ironstone with marine fossils. Lower third of Millstone Grit.
205. Joppa Shore, between tide-marks—marine ironstones—from 43 yds. to 46 yds. W. of the westmost corner formed by wall of salt pans. Lower third of Millstone Grit.
205*a*. Joppa Shore, a few yards W. of salt pans. Lower third of Millstone Grit.
206. Joppa Shore, opposite the Salt Works—opposite N.E. corner of salt pans. White cement band 1 to 2 in. thick. Upper two-thirds of Millstone Grit.
207. Joppa Shore, opposite the eastern corner of the house which is E. of the salt pans, within a few feet of the outcrop of Seven-Foot Coal. Lower Coal Measures.
208. Joppa Shore, E. of the salt pans, 4 to 8 yds. E. of E. corner of garden retaining wall on E. side of house—parroty shale overlying Four-Foot Coal. Lower Coal Measures.
209. Joppa Shore, E. of the salt pans, 193 ft. E. of E. corner of retaining wall of the garden on E. side of salt pans. (*Carbonicola* Bed.) Lower Coal Measures.
210. Musselburgh, Olivebank Pit sinking, S. of Fisherrow Harbour. Lower Coal Measures.
211. Levenhall Sandstone Quarry, S. side of road. Impure Coal 1 to 2 in. and shale overlying it—overlying the sandstone of the quarry. Upper two-thirds of Millstone Grit.
212. Levenhall Shore, at Buccleuch Park, at sewage pipe on shore—near high-water mark—coal cut off by E. & W. fault a few feet seawards. Upper two-thirds of Millstone Grit.
213. Levenhall Shore, at Buccleuch Park, east of foregoing locality—bed on W. side of gap in section. Upper two-thirds of Millstone Grit.
214. Levenhall Shore, at Buccleuch Park, east of foregoing locality, a few yards W. of West Pans—rocks obscured by sand and mud. Thin coal and marine shale above it. These are the same beds as those overlying the sandstones in the quarry. Upper two-thirds of Millstone Grit.
215. Levenhall Shore, at Buccleuch Park, east of the above locality. Sandstone on W. side of West Pans. Upper two-thirds of Millstone Grit.
216. Levenhall Shore, at West Pans. Lower third of Millstone Grit.
217. Levenhall Shore, at West Pans, 75 yds. E. of foregoing locality at E. corner of wall which projects on to the shore. (Marine Bed.) Lower third of Millstone Grit.
218. Levenhall Shore, E. side of West Pans, first exposure W. of the stream (= Parliamentary and Borough boundary) at Ravenshaugh Bridge. Lower third of Millstone Grit.
219. Carberry Colliery, 2 miles S.E. of Musselburgh. Edge Coals.
220. Wallyford Colliery, 1½ miles E. of Musselburgh. Edge Coals.
221. Dolphingston Pit, Prestongrange, shale associated with Diamond seam. Edge Coals.
222. Prestongrange Colliery, Prestonpans. Edge Coals.
223. Prestongrange, shore opposite, at Bankfoot, W. of Prestonpans. No. 5 Limestone and Shale. Upper Limestones.
224. Cuthill, W. of Prestonpans, where road bends sharply—beds between Nos. 4 and 5 Limestones. Upper Limestones.

225. Prestongrange Shore, W. end of Prestonpans. No. 4 Limestone.
226. Prestonpans, Northfield Pit, S. side of town. Edge Coals.
227. Crossgatehall, railway cutting at, 2½ miles N.E. of Dalkeith. Lower Limestones.
228. Cousland Quarries, 3 miles E.N.E. of Dalkeith. No. 2 Limestone. Lower Limestones.
229. Airfield trial quarry, near Cousland. Lower Limestones.
230. Airfield Farmhouse, quarry on W. side of, ¼ mile S.E. of Cousland. No. 2 Limestone. Lower Limestones.
231. Chalkieside Old Quarry, near Crossgatehall, 2½ miles N.E. of Dalkeith. Lower Limestones.
232. D'Arcy Quarry, 1¾ miles E. of Newton Grange and 2½ miles S.E. of Dalkeith. Lower Limestones.
233. Mayfield Quarry, 2 miles S.E. of Dalkeith. Lower Limestones.
234. Mansfield Quarry, 3 miles S.E. of Dalkeith. Lower Limestones.
235. Currielee, No. 3 quarry, river Tyne, 4 miles S.E. of Dalkeith. Lower Limestones.
236. Currielee, No. 2 quarry, right bank, 20 to 30 ft. above river Tyne, No. 2 Limestone. Lower Limestones.
237. Currielee, No. 1 quarry—quarry farthest up the Tyne. Lower Limestones.
238. Vogrie House, stream on N. side of, 3¾ miles S.E. of Dalkeith, below the fault where radiating structure is seen in sandstone. Lower Limestones.
239. Borthwick Castle, near, 2 miles S.E. of Gorebridge, Middleton South Burn, left bank, a few yards up stream from the bridge to the Castle.

B. GENERAL LIST OF CARBONIFEROUS FOSSILS ARRANGED IN THEIR SYSTEMATIC ORDER.

As already stated, a number of the species given in the lists are not represented by specimens in the Geological Survey Collection, but are taken from the published papers of the following authors: Messrs. Bennie and Kidston, Davidson, Etheridge, jun., Huxley, Jones and Woodward, Kidston, Lyddeker, Nicholson and Foord, T. Stock, Traquair. Such quotations are denoted respectively by the initials BK, D, E, H, JW, K, L, NF, S, T, placed immediately after the locality number of the species recorded :—

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
ALGÆ.								
Spirophyton *Hall.*								
,, cauda-galli *Vanuxem* .		×						160.
FILICALES.								
Alethopteris *Sternberg.*								
,, decurrens *Artis* . . .							×	197, 198, 210.
,, lonchitica *Schl.* . . .						×	×	96, 114K, 117*a*, 122, 125, 140, 171 ?, 188, 192, 197, 207, 210.
,, sp. indet.						×		171 ?.
Archæopteris *Dawson* ?.								
,, tschermaki, *Stur.* . .		×						3.
Calymmatotheca—see Telangium.								
Cardiopteris *Schimper.*								
,, ? frondosa *Göpp.*	×							27, 30K, 32, 33.
,, polymorpha *Göpp.* . .	×							30K, 32, 33, 56, 67.
,, ,, *var.* rotundifolia *Göpp.*	×							5.
,, sp. indet.	×							27, 31, 39, 55, 61, 82.
Eremopteris *Schimper.*								
,, artemisæfolia *Sternb.* .							×	190, 195*a*, 196.
Mariopteris *Zeiller.*								
,, muricata *Schl.* . . .						×	×	125, 188, 192, 207, 210.
Neuropteris *Brongniart.*								
,, impar *Weiss* sp. . . .							×	125, 196 ?.
,, *cf.* blissii *Lx.* . . .							×	190.
,, gigantea *Stbg.* . . .						×	×	96K, 124 ?, 125, 130, 192, 195*a*, 196, 197, 199.
,, heterophylla *Brong.* . .						?	×	117, 125, 196, 198, 206 ?.
,, rectinervis *Kidst.* . .							×	114K.
,, sp. indet.						×	×	96, 122, 125, 189, 206, 210.
Rhacopteris *Schimper.*								
,, inæquilatera *Göpp.* . .	×							18, 38, 44K, 48, 50, 84.
,, lindseæformis *Bunb.* . .	×							44K, 49, 50, 51, 52K, 54, 61K, 64K, 65, 79.
,, transitionis *Stur.* . .	×							41, 64.
Renaultia *Zeiller.*								
,, gracilis *Brongt.* . . .							×	125K.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
FILICALES—*continued.*								
Sphenopteris *Brongniart.*								
,, acuta *Brong.*							×	192.
,, bermudensiformis *Schl.*		×						161.
,, crassa *L. & H.*	×							50, 51, 87K, 89K.
,, decomposita *Kidst.*	×							22, 30K.
,, dicksonioides *Göpp.*			×					7*a*.
,, *cf.* divaricata *Göpp.* sp.	×							2.
,, dunsii *Kidst.*	×							30, 44K, 49K, 58K, 64K, 89K.
,, elegans *Brong.*	×		×	×	×			7*a*, 8, 17*a*K, 108, 169 ?, 180*a*, 218, 224, 226.
,, foliolata *Stur.*	×		×					2, 169.
,, hibberti *L. & H.*	×							27K ?, 30K ?, 64K, 78, 89K ?.
,, höninghausi *Brong.*							×	114K, 125, 190.
,, latifolia *Brong.*							×	96, 114K, 125.
,, larischi *Stur.* sp.				×				109.
,, linkii *Göpp.*				×	×			109, 128, 224.
,, obovata *L. & H.*	×							22, 27, 33, 50, 52K, 84.
,, obtusiloba *Brong.*						×	×	96, 125, 129, 195*a*, 196, 207 ?.
,, ? schimperiana *Göpp.*	×							44K.
Telangium *Benson.*								
= (Calymmatotheca *Stur.*)								
= (Sphenopteris *Brong. in part*)								
,, affine *L. & H.* sp.	×							2, 5K, 22K, 27, 29, 30, 33, 38, 39, 43, 44, 45, 46, 48, 49, 50, 51, 53, 56, 57, 60, 64, 66, 67*a*, 69, 72, 73, 76, 77, 78, 79, 80, 82, 84, 87, 89.
,, bifidum *L. & H.* sp.	×							22, 89K.
Urnatopteris *Kidston.*								
,, tenella *Bgt.* sp.							×	190.
EQUISETALES.								
Asterocalamites *Schimper.*								
,, scrobiculatus *Schl.* sp.	×		×	×	×			18*a*K, 22, 27, 30, 31K, 32, 36, 38, 43, 44, 45, 49, 50, 54, 59, 61, 64K, 66, 67*a*, 69, 77, 79, 84, 89, 135, 136, 220, 224.
,, cone(Pothocites *Paterson*)	×							29K, 30K, 31K.
Calamites *Suckow.*								
,, cistii *Brong.*							×	117, 125, 193.
,, haueri *Stur.*				×	×			109, 118, 128, 174, 218.
,, ramifer *Stur.*				×	×	×		108, 109, 117*a*, 118, 124 ?, 126 ?, 174, 177.
,, ramosus *Artis.*							×	117, 125, 197.
,, ? rœmeri *Göpp.*	×							56K.
,, suckowii *Brong.*						×	×	117, 125, 130, 193, 197.
,, undulatus *Sternb.*							×	117, 125, 192, 198.
,, varians *Stbg. var.* insignis *Weiss.*							×	117, 210.
,, waldenburgensis *Stur.* = approximatus *Brong.* in part.							×	125K.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
EQUISETALES—*continued.*								
Calamites nov. sp.				×	×			108, 109, 118, 120, 126, 127 ?, 128, 147, 173, 218, 224.
,, sp. indet.					×			174, 176.
Annularia *Sternberg.*								
,, radiata *Brong.*						×	×	114K, 125, 140, 146, 190, 192, 193, 207.
Calamocladus *Schimper.*								
,, equisetiformis *Schl.*						×	×	122, 125, 129, 140.
,, longifolius *Sternb.*							×	114K.
Palæostachya *Weiss*								
,, ettingshauseni *Kidst.*								125.
Pinnularia *Lindley & Hutton.*							×	
,, capillacea *L. & H.*								125.
							×	
SPHENOPHYLLALES.								
Sphenophyllum *Brongniart.*								
,, cuneifolium *Stbg.*							×	125, 210.
,, ,, var. saxifragæfolium *Brong.*							×	125K.
,, tenerrimum *Ett.*			×	×	×			108, 128, 218, 219, 224.
,, sp. indet.	×							45.
LYCOPODIALES.								
Bothrodendron, *Lindley & Hutton.*								
,, depereti *Vaffier.*	×							85, 86.
,, wünkianum *Kidst.*	×							30K, 50K.
Lepidodendron *Sternberg.*								
,, aculeatum *Stbg.*						×	×	125K, 180.
,, ellipticum *Göpp.*	×							38, 59, 60K, 75K.
,, glincanum *Kidst. non Eichd.*					×	×		111, 177.
,, landsburgii *Kidst.*							×	125K.
,, lycopodioides *Stbg.*							×	125.
,, obovatum *Stbg.*					?	×	×	125, 180, 204 ?, 209, 211, 212, 214.
,, ophiurus *Brongt.*							×	125K.
,, rhodeanum *Stbg.*	×				×			75K, 89K, 111, 119, 126, 174, 204, 218.
,, rhodumense *Renault.*	×							20*a*.
,, rimosum *Stbg.*							×	125.
,, spetsbergense *Nath.*	×							80K.
,, veltheimi *Stbg.*	×		×		×	×		2, 4, 8K, 26, 27, 30, 38, 41K, 44K, 49, 50, 59, 64, 69, 80K, 84, 85, 86, 87, 89K, 98K, 119, 138, 143, 169, 170, 174, 175, 176, 215, 218, 220, 222.
,, volkmannianum *Stbg.*	×	×						86*a*K, 238.
Lepidophloios *Sternberg.*								
,, acerosus *L. & H.*							×	125, 207.
,, *cf.* harcourti *Witham.*	×							28K, 39K.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
LYCOPODIALES—*continued.*								
Lepidophloios scoticus *Kidst.*	×			×				30, 37, 38, 41, 43, 47, 48, 50, 52, 54, 64K, 79, 80K, 85, 224.
,, sp. indet.						×	×	177, 207.
Sigillaria *Brongniart.*								
,, canobianum *Kidst.*					×			111.
,, elegans *Stbg.*						×		212.
,, mammillaris *Brong.*							×	113.
,, ,, var. dournaisii *Brong.*							×	113.
,, scutellata *Bgt.*						×	×	113, 206.
,, sillimanni *Bgt.*						×	×	113, 180 ?.
,, taylori *Carr.*	×				×			64K, 76K, 80K, 87K, 174 ?, 204 ?.
,, *cf.* undulata *Göpp.*					×			111.
,, sp. indet.							×	196.
Stigmaria *Brongniart.*								
,, ficoides *Brongt.*	×		×		×	×	×	64, 125, 126, 169, 170, 173, 174, 177, 179, 191, 211.
,, ,, *var.* rimosum *Gold*			×		×			90, 118.
,, ,, var.					×	×		133, 176, 211.
,, stellata *Göpp.*			×		×			90, 218, 226 ?.
Lepidophyllum *Brongniart.*								
,, intermedium *L. & H.*	×		×					30, 33, 44, 45, 48, 50, 57, 66, 75, 78, 169.
,, lanceolatum *L. & H.*	×							22, 33, 38, 64.
,, sp. indet.	×				×			4, 37, 52, 132.
Lepidostrobus *Brongniart.*								
,, comosus *L. & H.*	×							43, 64, 65.
,, variabilis *L. & H.*	×		×		×	×	×	47, 48, 49, 51, 52, 64, 111, 125, 177, 219.
,, sp. indet.	×					×	×	× (Mid. Coal Meas.) 4, 30, 31, 38, 41, 44, 45, 54, 59, 61, 64, 66, 69, 78, 79, 85, 86, 87, 96, 195, 213.
CORDAITEÆ.								
Cordaites *Unger.*								
,, principalis *Germar*						×	×	117, 117*a*, 122, 124 ?, 125, 130, 146, 171, 193, 197, 199, 206 ?, 207, 213.
,, sp. indet.	×							25, 27, 31, 39, 58.
Sternbergia *Artis.*								
,, approximata *Brong.*						×	×	117, 211.
Pitys *Witham, emend.* (Araucarioxylon *Kraus.*).								
,, primæva *Witham*	×							62K.
,, withami *L. & H.*	×							28.
SEEDS, ETC.								
Carpolithus *Sternberg.*								
,, *cf.* ovatus *Schenk.*						×		124*a*.
,, perpusillus, *Lx.*							×	125, 195*a*.
,, sulcatus *L. & H.*	×							30, 50, 51, 54, 56.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
SEEDS, ETC.—*continued.*								
Carpolithus sp. indet.	×						×	38, 44, 46, 48, 49, 67, 195*a*.
Cordaianthus, *Grand'Eury.*								
,, pitcairniæ, *L. & H.* sp.						×	×	117*a*, 125, 146.
Rhabdocarpus *Göpp. & Berg.*								
,, sp. indet.							×	146.
Samaropsis *Göppert.*								
,, acuta *L. & H.* sp.	×						×	195*a*, 196.
,, sp. indet.						×	×	123, 124, 129, 130, 190, 195*a*.
Trigonocarpus *Brongniart.*								
,, parkinsoni *Brong.*							×	125.
,, sp. indet.	×	×				×		4, 206, 234.
SPORES.								
Lagenicula *Kidston.*								
,, I.	×	×		×				25BK, 227BK, 203, 91*a*BK, 44BK.
Triletes *Reinsch.*								
,, I.							×	111*a*BK, 113BK.
,, II.							×	113BK.
,, II. var.							×	113BK.
,, V.					×			91*b*BK.
,, VI.					×		×	91*b*BK, 205*a*BK, 112*a*BK.
,, VII.					×		×	205*a*BK, 113BK.
,, IX.					×	×	×	91*b*BK, 206, 111*a*BK, 113BK.
,, X.							×	111*b*BK, 112BK, 112*a*BK, 113BK.
,, XI.							×	111*a*BK, 112BK, 112*a*BK, 113BK.
,, XII.					×			91*b*BK, 205*a*BK.
,, XIV.					×			205*a*BK.
,, XV.					×			91*b*BK, 205*a*BK.
,, XVI.		×		×				106*a*BK, 107*a*BK.
,, XVII.							×	111*a*BK, 112*a*BK.
,, XVIII.					×			205*a*BK ?.
INCERTÆ SEDIS.								
Calcisphæra *Williamson.*								
,, sp. indet.	×							18.
Schutzia *Geinitz.*								
,, bennieana *Kidst.*	×							49BK.
FORAMINIFERA.								
Climacammina *H. B. Brady.*								
,, antiqua *H. B. Brady*		×						144, 145, 163, 184.
,, sp. indet.		×						145.
Endothyra *Phillips.*								
,, ammonoides *H. B. Brady*		×						151.
,, bowmani *Phil.*		×						151.
,, crassa *H. B. Brady*		×						144 ?, 163, 184.
,, globulus (*d'Eichw.*)		×						1, 144, 145, 151, 184.
,, macella *H. B. Brady*		×						14 ?, 145 ?.
,, radiata *H. B. Brady*		×		×				144, 145, 223.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
FORAMINIFERA—*continued.*								
Lituola *Lamarck.*								
„ bennieana *H. B. Brady* . .		×						144, 163.
Saccammina *Sars.*								
„ carteri *H. B. Brady* . .		×						16, 144, 145, 151, 160 ?; 168, 237.
Stacheia *H. B. Brady.*								
„ congesta *H. B. Brady* . .		×						151.
„ polytrematoides *H. B. Brady* .		×						1, 157.
„ sp. indet.		×						144.
Textularia *Defrance.*								
„ eximia *d'Eich.* . . .		×		×				14, 16, 145, 163 ?, 223 ?.
„ gibbosa *d'Orb.* . . .		×						163.
Trochammina *Parker & Jones.*								
„ incerta *d'Orb.* . . .		×						1, 14, 151, 228, 232.
Valvulina *d'Orbigny.*								
„ decurrens *H. B. Brady* . .		×						145, 157, 168, 184, 228.
„ palæotrochus *H. B. Brady* .		×						1, 14, 16 ?, 144, 145, 157, 160, 163, 165, 168, 228.
„ „ var. compressa *H. B. Brady* .		×						1, 145, 168.
„ plicata *H. B. Brady* . .		×						151, 184.
„ youngi *H. B. Brady* . .		×						157.
Onion-like bodies (*Foraminifera* ?) . .		×						160, 165.
PORIFERA.								
Hyalostelia *Zittel.*								
„ parallela (*M'Coy*) . .		×						1, 15, 150, 157, 229.
„ smithi (*Young*) . . .		×						1, 157.
„ sp. indet.		×						160.
Sponges indet.	×	×		×				64, 71, 139, 160.
INCERTÆ SEDIS								
Palæacis *Edw. & Haime.*								
„ cyclostoma (*Phill.*) . .		×						1, 14, 157, 228, 231.
ECHINODERMATA.								
Crinoidea.								
Actinocrinus *Miller.*								
„ sp. indet.		×						168, 227, 237.
Dichocrinus *Münster.*								
„ sp. indet.		×						157.
Hydreionocrinus *de Kon.*								
„ globularis *de Kon.* .		×		×				139, 157 ?, 166, 168, 233, 237 ?.
„ sp. indet. . . .		×						1, 144, 227, 231.
Platycrinus *Miller.*								
„ *cf.* lævis *Mill.* . . .		×						157.
„ trigintidactylus *Austin* .		×						1.
„ sp. indet.		×						15, 163, 166.
Poteriocrinus *Miller.*								
„ crassus *Mill.* . . .		×						151, 156, 163, 227, 228, 232.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
ECHINODERMATA—*continued.*								
Poteriocrinus *cf.* nuciformis *M'Coy*		×						157.
,, sp. indet.		×		×				144, 145, 154, 160, 237.
Rhodocrinus *Miller.*								
,, *cf.* bursa (*Phill.*)		×						151.
,, sp. indet.		×						157, 166.
Pear-shaped crinoid		×						16, 151, 160.
Crinoid ossicles		×	×	×	×			13, 14, 100, 102, 106, 131, 139, 144, 145, 151, 157, 158, 159, 163, 164, 167, 169, 172, 178, 203, 216, 223, 228.
Blastoidea.								
Zygocrinus *Bronn.* [Astrocrinites *auctt.*].								
,, benniei (*R. Eth., junr.*)		×						151, 157.
Echinoidea.								
Archæocidaris *M'Coy.*								
,, urei (*Flem.*)		×			×			1, 145, 157, 160, 172, 228, 232.
,, sp. indet.		×	×	×				6, 7, 14, 15, 16, 99, 100, 105, 144, 150, 151, 154, 157, 165, 168, 203, 223, 228, 235, 237.
Holothuridea.								
Achistrum *R. Etheridge, junr.*								
,, nicholsoni *R. Eth., junr.*		×						157.
Cheirodota *Eschscholtz.*								
,, robertsoni *R. Eth., junr.*		×						14.
,, traquairi *R. Eth., junr.*		×						14, 157.
Holothurian plates indet.		×		×				157, 223.
ANNELIDA.								
Ortonia *Nicholson.*								
,, carbonaria *Young*		×						99, 100, 145, 160, 165.
Serpula *Linnæus.*								
,, sp. indet.		×						236.
Serpulites *M'Leay.*								
,, carbonarius *M'Coy*	×	×						61, 160, 165. 228, 233.
,, sp. indet.	×	×		×				1, 38, 61, 145, 150, 157, 223.
Spirorbis *Lamarck.*								
,, ambiguus *Flem.*		×						1, 157.
,, caperatus *M'Coy*		×						1, 5, 32, 43, 50, 51, 53, 64, 144, 145, 157, 163, 165.
,, pusillus (*Mart.*)	×							18, 25, 27, 29, 32, 43, 52, 53, 55, 63, 64, 66, 69, 78, 79, 83, 87, 89.
,, ,, var. hibberti *R. Eth., junr.*	×							89.
,, helicteres *Salt.*	×	×						18, 63, 71, 236.
,, spinosa (*de Kon.*)		×						16, 157, 160.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
ANNELIDA—*continued.*								
Spirorbis sp. indet.	×	×					×	25, 32, 41, 43, 100, 103, 116, 144, 145, 151, 191, 228.
Vermilia *Lamarck.*								
,, minuta *Brown*		×						228.
ARTHROPODA.								
Ostracoda.								
Aglaia *Brady.*								
,, cyprididformis *J. & K.*	×							18.
Argillœcia *Sars.*								
,, æqualis *J. & K.*	×	×						4, 18, 67 ?, 235.
Bairdia *M'Coy.*								
,, ampla *Reuss.*		×						144, 157, 160 ?, 166, 184, 232.
,, brevis *J. & K.*		×						1, 165, 166, 184.
,, circumcisa *J. & K.*		×						14.
,, curta *M'Coy*		×						1, 16, 100, 228 ?.
,, elongata (*Münst.*)		×						16, 144 ?, 145, 157, 235.
,, grandis *J. & K.*		×						151 ?.
,, hisingeri (*Münst.*)		×		×				1, 14, 144, 145, 151, 157, 166, 223, 233, 235.
,, mucronata *Reuss.*		×						234, 235.
,, plebeia *Reuss.*		×		×				1, 16, 145, 151, 157, 160, 163, 165, 166, 184, 223, 228, 232, 233, 235.
,, ,, var.		×						1, 184, 232, 235.
,, subcylindrica (*Münster*)		×						144, 145, 227, 233, 235.
,, subelongata *J. & K.*		×						1, 160, 165, 184.
,, submucronata *J. & K.*		×						1, 14, 160.
,, sp. indet.	×							75, 145.
Beyrichia *M'Coy.*								
,, arcuata (*Bean.*)	×	×						67, 227.
,, rigida *J. & K.*		×						14.
,, subarcuata *Jones*		×						227.
,, sp. indet.		×						160.
Beyrichiella *Jones & Kirkby.*								
,, ventricornis *J. & K.*		×						1 ?, 157.
Beyrichiopsis *Jones & Kirkby.*								
,, fimbriata *J. & K.*	×							4.
,, ,, var.	×							4.
,, sp. indet.	×							67.
Bythocypris *Brady.*								
,, bilobata (*Münst.*)	×							144 ?, 157, 163, 235.
,, cornigera *J. & K.*		×						1, 14, 157, 160.
,, cuneola *J. & K.*	×	×						14, 67, 151, 232, 235.
,, sublunata *J. & K.*	×							18 ?.
,, thraso ? *J. & K.*		×						233.
Carbonia *Jones.*								
,, fabulina (*J. & K.*)		×						15, 145, 227, 233, 235.
,, pungens (*J. & K.*)		×						14.
,, sp. indet.			×	×				10 ?, 223.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
ARTHROPODA—*continued.*								
Cythere *Müller.*								
,, intermedia *Münst.*	×	×						100, 163, 228, 233, 237.
,, superba *J. & K.*	×							4 ?.
,, sp. indet.		×						16, 165.
Cytherella *Jones.*								
,, inflata *Münst.*		×						166.
,, simplex *J. & K.*		×						233.
,, sp. indet.		×						1, 145, 157, 160, 165.
Entomoconchus *M'Coy.*								
,, scouleri *M'Coy*		×			×			167, 172.
Kirkbya *Jones.*								
,, permiana (*Jones*)		×						14, 145, 157, 160, 165, 235.
,, ,, var.		×						145.
,, plicata *J. & K.*		×						160.
,, spiralis *J. & K.*	×							18.
,, umbonata (*d'Eichw.*)		×						1, 14, 157, 160.
,, urei *Jones*		×						14, 232.
Leperditia *Rouault.*								
,, oblonga *J. & K.*		×						160.
,, okeni (*Münst.*)	×	×		×				14, 18, 67, 68, 145, 151, 166, 223, 235.
,, ,, var.		×						160.
,, scotoburdigalensis (*Hibbert*)	×							67, 79, 157*b*.
,, suborbiculata (*Münst.*)	×	×						14, 67, 79, 232, 235.
,, subrecta (*Portl.*)	×							18, 68.
,, wrightiana ? *J. & K.*	×							18.
Phyllopoda.								
Cyclus *de Koninck.*								
,, testudo *Peach*	×							157*c*.
Estheria *Strauss.*								
,, peachii *Jones*	×							20.
,, striata var. binneyana *Jones*	×							43, 69.
Leaia *Jones.*								
,, jonesi *R. Eth.*	×							33 ?, 34 ?.
,, leidyi (*Lea.*)							×	196.
,, sp. indet.	×						×	195*a*.
Phyllocaridæ.								
Dithyrocaris *Scouler.*								
,, sp. indet.	×	×						61E, 157.
Hibbertia *Jones & Woodward.*								
,, orbicularis *J. & W.*	×							89 J. W.
Schizopoda.								
Crangopsis *Salter* [Palæocrangon *Salt.*]								
,, elegans (*Peach*)	×							157*c*.
,, eskdalensis (*Peach*)	×							157*c*.
Palæmysis *Peach.*								
,, two new species	×							157*c*.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
ARTHROPODA—*continued.*								
Perimecturus *Peach.*								
,, stocki *Peach*	×							30.
,, nov. sp.	×							157c.
Tealliocaris *Peach* [Anthrapalæmon *Salter*]								
,, etheridgi (*Peach*)	×							27s.
Trilobita.								
Griffithides *Portlock.*								
,, mesotuberculatus *M'Coy*		×						158, 160, 166.
,, sp. indet.		×						151, 160, 162.
Phillipsia *Portlock.*								
,, eichwaldi (*Fischer de Waldheim*) var. mucronata *M'Coy*		×		×				139, 157, 163, 167, 203, 223, 228.
Arachnida.								
Eoscorpius *Meek & Worthen.*								
,, sp. indet.	×		×					36, 56, 61, 169.
Myriapod			×					169.
POLYZOA.								
Batostomellids [including Stenopora urei (*Young*)]		×						144, 145, 157, 160, 165, 166, 168, 228, 229, 233.
Cystodictya *Ulrich.*								
,, parallela (*Phill.*)		×						157.
Fenestella *Lonsdale.*								
,, membranacea (*Phill.*)				×				223.
,, plebeia *M'Coy*		×		×				100, 168, 223 ?, 236.
,, tuberculocarinata *R. Eth., junr.*		×						157.
Fistulipora *M'Coy.*								
,, incrustans (*Phill.*) [Berenicea megastoma *auctt.*]		×						1, 100, 150, 151, 157, 165, 166, 227, 228.
,, muscosa *Nicholson & Foord.*		×						228NF.
Goniocladia *R. Eth., junr.*								
,, cellulifera *R. Eth., junr.*				×				223.
Hyphasmopora *R. Eth., junr.*								
,, buski *R. Eth., junr.*		×						145, 151 ?, 184.
,, sp. indet.		×		×				160, 165, 184, 223, 228.
Pinnatopora *Vine.*								
,, pulcherrima (*M'Coy*) [Glauconome *auctt.*]		×						236 ?.
,, sp. indet.		×						16, 145, 151, 160, 165, 166, 184, 235.
Polypora *M'Coy.*								
,, sp. indet.		×						157, 166.
Rhabdomeson *Young.*								
,, gracile (*Phill.*)		×						151, 157.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
POLYZOA—*continued.*								
Rhabdomeson ? interporosa (*Phill.*)		×						157.
,, sp. indet.		×						1, 16, 145, 160, 165, 184, 236.
Rhombopora *Meek.*								
,, benniei (*R. Eth., junr.*)		×						100, 157, 160.
Synocladia *King.*								
,, carbonaria *R. Eth., junr.*		×						100 ?, 223.
,, sp. indet.		×		×				99, 223.
Polyzoal appendages formerly known as "Palæocoryne"		×						1, 14, 16, 144, 145, 150, 151, 157, 160, 165, 166, 168, 236.
BRACHIOPODA.								
Amboccelia *Hall.*								
,, urei (*Flem.*) [Spirifer *auctt.*]		×						100D, 144, 145, 228, 232, 233.
Athyrids [*cf.* Cleiothyridina roissyi *Davidson* non *L'Eveillé*]		×						1, 144, 145, 150, 151, 157, 158, 160, 162, 163, 165, 166, 167, 168, 228, 229, 230, 232, 237.
Camarophoria *King.*								
,, crumena (*Mart.*)		×						1D, 165.
Camarotœchia *Hall & Clarke.*								
,, ? sp.	×							157*a*.
Chonetes *Fischer de Waldheim.*								
,, buchiana *de Kon.* [*Davidson*]		×		×				1, 139 ?, 157.
,, laguessiana *de Kon.*		×		×				1, 139, 157, 167, 184, 203, 228, 230, 232.
,, polita *M'Coy*		×						14 ?, 100, 105, 106, 144, 145 ?, 157, 160, 165, 184, 228.
,, sp.						×		232.
Crania *Retzius.*								
,, quadrata *M'Coy*		×						157, 160, 168.
Dielasma *King.*								
,, gillingense (*Dav.*)		×						168D, 228D.
,, hastatum (*J. de C. Sow.*)		×						156, 157, 163, 168, 228, 232, 233, 237.
,, sacculum (*Mart.*)		×						159, 166, 233.
,, vesiculare (*de Kon.*)								1D.
Hustedia *Hall & Clarke.*								
,, radialis (*Phill.*)		×						1D, 144, 157, 166, 233.
Leptæna *Dalman.*								
,, analoga (*Phill.*)		×						1D, 100D, 228.
Lingula *Bruguière.*								
,, mytiloides *J. Sow.*	×	×	×	×	×			× (Mid. Coal Meas.) 6, 25, 27, 35, 70, 72, 110, 134, 147*a*, 152, 155, 174, 179, 217, 223, 228.
,, squamiformis *Phill.*	×	×	×	×				1*a*, 3, 6, 17, 70, 104, 152, 160, 162, 181, 182, 183, 185, 186, 187, 203, 221.
Martinia *M'Coy.*								
,, glabra (*Mart.*)		×						1, 142, 144, 150, 151, 158, 159, 168D, 228D, 233, 234, 236.
,, ovalis (*Phill.*)		×		×				1, 131, 150 ?, 157, 228 ?, 230.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
BRACHIOPODA—*continued.*								
Orbiculoidea *d'Orbigny.*								
,, nitida (*Phill.*) . . .	×	×	×		×			25, 61, 100, 142, 150, 152, 160, 172, 217, 228, 233, 236.
Orthotetids [the *Streptorhynchus crenistria* of the old Survey lists includes aseptate forms referable to the genus *Schuchertella* Girty. Septate forms belonging to *Derbyia* or to *Orthotetes* (emend. Girty) are probably also represented].		×		×	×			1, 17, 102, 106, 137, 139, 145, 153, 155, 157, 165, 166, 167, 168D, 172, 184, 203, 223, 228, 229, 230, 233, 234, 236.
Productus *J. Sowerby.*								
,, aculeatus (*Martin*) . .		×						1, 106, 151, 157, 163, 166, 167, 168, 184, 228, 230, 234, 236.
,, *cf.* burlingtonensis *Hall* [*Vaughan*] . . .	×							157*a*.
,, *cf.* corrugatus *M'Coy* . .		×						158, 168 ?, 184, 228, 234, 236.
,, costatus *J. de C. Sow.* . .		×		×	×			157, 163, 167, 172, 217, 227 ?, 228, 234.
,, muricatus *Phill.* . . .		×		×				139, 167D.
,, fimbriatus *J. de C. Sow.* .		×						236.
,, giganteus (*Martin*) . .		×		×				100, 102, 107 ?, 137 ?, 139, 150 ?, 151, 159 ?, 167, 203, 223.
,, ,, conical variety .				×				102, 172.
,, latissimus *J. Sow.* . .				×				91, 102, 107, 139, 141, 154, 155, 203, 223, 225.
,, form intermediate between P. giganteus and P. latissimus				×				154, 223.
,, longispinus *J. Sow.* . .		×		×			×	1, 15, 100, 102, 105, 106, 139, 142 ?, 144, 145, 150, 151, 153, 154, 155, 156, 157, 158 ?, 159, 160, 163, 166, 167, 168, 184, 194, 223, 227, 228, 231, 232, 233, 234, 236, 237.
,, punctatus (*Martin*) . .		×		×				1, 106, 144, 149, 150, 151, 157, 159, 162, 165, 166, 167, 168, 223, 228, 229, 230, 232, 233, 236.
,, elegans *M'Coy* . . .		×						145, 163, 234, 236.
,, scabriculus (*Martin*) . .		×	×	×				1 ?, 11, 131, 142, 150, 151 ?, 155, 156, 158, 160, 162, 165, 168, 233, 235, 236.
,, semireticulatus (*Martin*) .		×		×	×	×		1, 11 ?, 13, 15, 106, 131 ?, 139, 142, 144, 149 ?, 150, 151, 152, 154, 157, 157*a*, 158, 158*a*, 159, 160, 162, 164, 165, 166, 167, 168, 172, 184, 203, 205, 211, 214, 217, 223, 229, 230, 232, 233, 234, 236, 237.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
BRACHIOPODA—*continued.*								
Productus semireticulatus *var.* martini *J. Sow.*		×		×				139, 159, 160, 165.
„ spinulosus *J. Sow.*		×						1D, 159, 160.
„ (Etheridgina) complectens *R. Eth., junr.*		×						157.
Pugnax *Hall & Clarke.*								
„ pugnus (*Martin*) [Rhynchonella *auctt.*]		×						228D.
Reticularia *M'Coy.*								
? „ lineata (*Martin*) [Spirifer *auctt.*] [Includes aseptate forms referable to the genus *Squamularia* Gemmellaro. The presence of the true septate *Reticularia* could not be ascertained.]		×						1, 144, 145, 156, 158, 165, 166, 167, 168, 184, 228, 229, 233, 236, 237.
Rhipidomella *Oehlert.*								
„ michelini (*L'Eveillé*) [Orthis *auctt.*]		×		×	×			1, 102, 104, 107, 144, 151, 157, 158, 160, 166, 168, 172 ?, 228, 229, 230, 232, 237.
Rhynchonella *Fischer.*								
„ ? pleurodon (*Phill.*)	×	×						157*a*, 164, 228, 232, 233.
Schizophoria *King.*								
„ resupinata (*Martin*) [Orthis *auctt.*]		×		×				1, 11, 104, 106, 139, 142, 160, 165, 166, 167, 168, 223, 228, 229, 230, 236, 237.
Seminula *M'Coy.*								
„ ambigua (*J. Sow.*) [Athyris *auctt.*]	×	×		×				1, 139, 144, 145, 151, 155, 156, 157*a*, 163, 166, 167, 168, 228, 237.
„ sp.					×			110*a*.
Spirifer *J. Sowerby.*								
„ duplicicosta, *Phill.*		×						1 ?, 162, 228, 229, 236.
„ trigonalis (*Martin*)		×		×	×			102, 105, 106, 131, 144, 149, 151, 154, 156, 157, 158, 159, 160, 162, 165, 166, 167, 168, 172, 184, 216, 217, 223, 227, 228, 229, 230, 232, 233, 234, 236 ?, 237.
„ „ *var.* bisulcata *J. de C. Sow.*		×		×				1, 107, 131, 139, 159, 160, 166, 227, 232.
Spiriferina *d'Orbigny.*								
„ cristata (*Schloth.*) *var.* octoplicata (*J. de C. Sow.*)		×		×				1, 102, 150, 157, 223, 236.
„ insculpta (*Phill.*)		×						157.
LAMELLIBRANCHIATA.								
Actinopteria *Hall.*								
„ fluctuosa (*R. Eth., junr.*)		×						3.
„ persulcata (*M'Coy*)	×	×						3, 17, 74, 104, 142, 160, 165, 167.
„ sp. indet.								1*a*.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
LAMELLIBRANCHIATA—*continued.*								
Allorisma *King.*								
,, variabilis (*M'Coy*) . .		×	×					6, 151, 236.
Anthracomya *Salter.*								
,, adamsi *Salter* . . .	×							38.
,, lævis *Dawson, var.* scotica *Eth.*	×							5, 43, 50, 69, 87, 89.
,, valenciensis *Hind* . .	×					×		39, 177 ?.
,, wardi *Salter* MSS. . .			×					9.
,, sp. indet. . . .	×							55.
Aviculopecten *M'Coy.*								
,, dissimilis (*Flem.*) . .	×	×	×	×	×			1, 13, 147*a*, 150, 152, 157*a*, 158 ?, 159, 160, 167, 169, 172, 228, 233, 236.
,, forbesi (*M'Coy*) . .	×	×						157*a*, 236.
,, inæqualis *Hind* . .		×						6.
,, interstitialis (*Phill.*) .		×		.				11, 147*a*, 160.
,, knockonniensis (*M'Coy*) .		×						236.
,, neglectus (*Geinitz*) . .					×			110*a*.
,, obliquus *Hind* . .					×			110*a*.
,, regularis *Hind* . .					×			110*a*.
,, subconoideus *R. Eth., junr.*	×	×						27, 160 ?.
,, sp. indet. . . .	×	×		×				70, 99, 106, 150, 155, 157*a*, 162, 184, 223.
Carbonicola *M'Coy.*								
,, acuta (*J. Sow.*) . .					?		×	95, 201, 217 ?.
,, antiqua *Hind* . . .	×							44 ?.
,, robusta (*J. de C. Sow.*) .							×	95, 112, 114 ?, 115, 116, 191, 209.
Cardiomorpha *de Koninck.*								
,, sp. indet. . . .	×	×						3*a*, 228.
Conocardium *Bronn.*								
,, inflatum (*M'Coy*) . .		×						160.
,, sp. indet. . . .		×						100.
Ctenodonta *Salter.*								
,, lævirostris (*Portl.*) . .			×		×			6, 110*a*.
,, sp. indet. . . .		×						232.
Cypricardella *Hall.*								
,, acuticarinata (*Armstrong*)		×			×			157, 172.
,, concentrica *Hind* . .		×						100.
,, rectangularis (*M'Coy*) .	×	×						30, 157.
Edmondia *de Koninck.*								
,, excentrica *Hind* . . .					×			110*a*.
,, expansa *Hind* . . .		×						160.
,, laminata (*Phill.*) . .	×	×						61, 160.
,, *cf.* lyelli *Hind* . . .		×						167.
,, maccoyi *Hind* . . .		×			?			152, 178.
,, *cf.* oblonga (*Portl.*) . .				×				223.
,, primæva (*Portl.*) . .		×						228.
,, rudis *M'Coy*. . . .	×							75, 157*a*, 157*d*.
,, sulcata (*Phill.*) . . .		×						152.
,, scalaris (*M'Coy*) . . .	×							3*a* ?.
,, senilis (*Phill.*) [dwarf] .					×			110*a*.
Grammatodon *Meek & Hayden* [Parallelodon *auctt.*].								

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
LAMELLIBRANCHIATA—*continued.*								
Grammatodon geinitzi (*de Kon.*)	×				×			61, 172.
,, tenuistriata (*M. & W.*)					×			110*a*.
,, sp. indet.	×	×						61, 100, 102.
Leiopteria *Hall.*								
,, divisa (*M'Coy*)	×							25, 61.
,, lunulata (*Phill.*)		×						167, 168 ?.
,, thompsoni (*Portl.*)		×			×			172, 184.
Lithodomus *Cuvier.*								
,, lingualis (*Phill.*)		×	×					142, 161, 162, 165.
Modiola *Lamarck.*								
,, macadami *Portlock*	×							157*a*.
Myalina *de Koninck.*								
,, sublamellosa *R. Eth., junr.*	×	×						25, 152, 157*a*.
,, verneuili (*M'Coy*)	×	×	×		×			6, 61, 110*a*.
Naiadites *Dawson.*								
,, carinata (*J. de C. Sow.*)							×	185, 200, 210, 226.
,, crassa (*Flem.*)	×							59, 61.
,, elongata *Hind*							×	209.
,, modiolaris (*J. de C. Sow.*)	×		×				×	61, 103, 185, 210, 226.
,, obesa (*R. Eth., junr.*)	×		×					2*a*, 6, 8*a*, 9, 10, 23, 24, 26, 27, 29, 30, 36 ?, 38, 44, 67, 67*a*, 220, 239.
,, sp. indet.	×							6, 157*a*.
Nucula *Lamarck.*								
,, gibbosa *Flem.*	×	×	×	×				1, 6, 15, 26, 105 ?, 151, 157, 223.
,, oblonga *M'Coy*	×							63 ?.
,, scotica *Hind*	×							61.
Nuculana *Link.*								
,, attenuata (*Flem.*)	×	×		×	×			1, 61, 102, 110*a*, 149, 152, 156, 157, 157*d*, 160, 223, 228.
,, brevirostris (*Phill.*)	×							61.
,, lævistriata (*Meek & Worthen*)	×							59.
,, sharmani *R. Eth., junr.*	×							61.
,, sp. indet.				×				155.
Palæolima *Hind.*								
,, simplex (*Phill.*)					×			172.
,, sp.	×							157*a*.
Pinna *Linné.*								
,, flabelliformis (*Mart.*)		×	×					6, 13, 150, 161, 167, 236.
,, mutica *M'Coy*				×				147*a*.
,, sp. indet.		×						168, 184.
Posidonomya *Bronn.*								
,, corrugata *R. Eth., junr.*		×						1*a*, 3, 100.
,, sp. indet.	×	×						3*a*, 15, 104, 228.
Protoschizodus *de Koninck.*								
,, axiniformis (*Portl.*)		×			×			3, 105, 157*a*, 167 ?, 172.
,, nuculoides (*M'Coy*)	?							27.
,, obliquus (*M'Coy*)			×	×				6, 155, 156.
,, sp. indet.	×	×						8, 100.
Pseudamusium *H. & A. Adams, after Klein; emend Verrill.*								
,, anisotum (*Phill.*)		×						165.
,, ellipticum (*Phill.*)		×						1*a* ?.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
LAMELLIBRANCHIATA—*continued.*								
Pterinopecten *Hall.*								
,, papyraceus (*J. Sow.*)					×			110*a*.
,, tessellatus (*Phillips*)		×						165.
Pteronites *M'Coy* (*pars*).								
,, angustatus *M'Coy*	×				×			61, 172.
Sanguinolites *M'Coy.*								
,, abdenensis *R. Eth., junr.*	×	×						3 ?, 27 ?, 63, 158*a*.
,, angulatus *de Kon.*				×				155.
,, angustatus *Phill.*		×						17.
,, clavatus (*R. Eth., junr.*)	×	×						23, 26, 27, 30, 35, 61, 151.
,, costellatus (*M'Coy*)		×	×					16, 100.
,, plicatus (*Portl.*)	×	×	×					1*a*, 6 ?, 15, 63 ?, 152.
,, roxburgensis *Hind*	×							27.
,, striatus *Hind*	×	×						26, 164 ?.
,, tricostatus (*Portl.*)		×						100 ?, 236.
,, Vscriptus *Hind*	×							3*a*.
,, sp. indet.		×		×				13, 106, 141, 152, 160, 184, 223.
Sedgwickia *M'Coy.*								
,, gigantea *M'Coy*	×	×			?			100, 157*a*, 172 ?.
,, ovata *Hind*		×						100.
,, sp. indet.		×						233, 236.
Schizodus *King.*								
,, antiquus *Hind*					×			172.
,, pentlandicus (*Rhind*)	×		×					6, 26, 27, 35 ?, 36, 59, 61.
,, wheeleri (*Swallow*)					×			110*a*.
Solenomya *Lamarck.*								
,, costellata (*M'Coy*)		×			?			17, 160 ?, 172 ?.
,, primæva *Phill.*		×						106, 160, 167, 184, 234.
Streblopteria *M'Coy.*								
,, ornata (*R. Eth., junr.*)		×						1*a*, 3, 17 ?, 104, 152, 158*a*.
Syncyclonema *Meek.*								
,, sowerbyi (*M'Coy*)		×	×					3, 100, 142, 156, 157*a*, 160, 165, 167, 184, 228, 233, 234.
GASTEROPODA.								
Agnesia *de Kon.*								
,, thomsoni *de Kon* [A. contraria *auctt.* non *de Kon.*]		×						151.
Bellerophon *de Montfort.*								
" Bellerophon " marcouianus *Geinitz*					×			110*a*.
,, undatus *R. Eth., junr.*	×							31.
Bucanopsis *Ulrich.*								
,, decussata (*Flem.*) [Bellerophon *auctt.*]	×	×		×				27, 35, 61, 105, 145, 157, 157*d*, 160, 223, 233, 236.
,, striata (*Flem.*) [Bellerophon *auctt.*]	×	×		×				3*a*, 155, 160.
Capulus *Montfort* [Platyceras and Acroculia *auctt.*].								
,, angustus (*Phill.*)		×						160 ?.
,, neritoides (*Phill.*)		×						228, 229.
Dentalium *Linnæus.*								
,, sp. indet.		×		×				14, 155.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
GASTEROPODA—*continued.*								
Euomphalus *J. Sowerby.*								
,, carbonarius *J. de C. Sow.*		×		×				141, 228.
,, marginatus *M'Coy*		×						228.
Euphemus *M'Coy.*								
,, urei (*Flem.*) [Bellerophon *auctt.*]		×	×					1*a*, 6, 14 ?, 17, 100, 105, 156, 228, 231, 232.
,, orbignyi (*Portlock*)					×			110*a*.
Macrochilina *Bayle.*								
,, acuta (*J. de C. Sow.*)				×				102.
,, michotiana *de Kon.*		×						228 ?.
,, rectilinea (*Phill.*)	×							3*a*.
Murchisonia *d'Arch. & de Vern.*								
,, angulata (*Phill.*)				×	?			102, 157, 172 ?.
,, striatula *de Kon.*		×						1, 14, 151 ?.
Naticopsis *M'Coy.*								
,, variata (*Phill.*)		×						11, 13 ?, 15, 106, 151 ?, 233, 236.
Platyostomella *Etheridge, Junr.*								
,, scotoburdigalensis *Eth., Junr.*	×							23, 52, 64.
Porcellia *Leveillé.*								
,, puzo *Lev.*		×						157.
Ptychomphalina *Bayle.*								
,, atomaria (*Phill.*)	×							3*a*.
,, monilifera (*Phill.*)	×							61, 157*d*.
,, striata (*J. Sow.*) [Pleurotomaria *auctt.*]				×				102.
Schizostoma *Bronn.*								
,, catillum (*Martin*) [Euomphalus *auctt.*]	×							157*a*.
Tropidocyclus *de Kon.*								
,, oldhami (*Portlock*) [Bellerophon *auctt.*]		×						1.
Yvania *Bayle.*								
,, yvani (*Lev.*) [Pleurotomaria *auctt.*]		×						157 ?, 184, 234.
Zygopleura *Koken* [Loxonema *auctt.*]								
,, rugiferum (*Phill.*)		×						151, 157, 228, 234 ?.
,, scalarioideum (*Phill.*)		×						157.
INCERTÆ SEDIS.								
Conularia *Miller.*								
,, quadrisulcata *J. Sow.*		×						1, 14, 100, 157.
,, sp. indet.		×						157, 236.
CEPHALOPODA.								
Nautiloidea.								
Actinoceras *Bronn.*								
,, giganteum (*J. Sow.*)		×						167.
,, sowerbyi (*M'Coy*)	×							3*a*.
,, sp. indet.		×						157.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
CEPHALOPODA—*continued.*								
Cœlonautilus *Foord.*								
,, planotergatus (*M'Coy*) .	×							3*a*.
,, quadratus (*Flem.*)[Discites *auctt.*]		×						160, 167, 184, 228, 232, 234.
Coloceras *Hyatt.*								
,, coyanum (*d'Orb.*) . . .	×							3*a*.
Cyrtoceras *Goldfuss.*								
,, rugosum *Flem.*		×						160, 233.
Orthoceras *Breynius.*								
,, attenuatum *Flem.* . .	×							27, 61.
,, cylindraceum *Flem.* . .	×	×						3*a*, 14 ?, 157.
,, pyramidale ? *Flem.* . .	×							3*a*.
,, sulcatum *Flem.* . . .		×						1, 3*a*, 14, 160, 184 ?, 228.
,, sp. indet.	×	×		×				15, 17, 27, 30, 35, 37, 59, 61, 100, 105, 151, 156, 157, 157*a*, 158, 167, 203, 223, 234.
Pleuronautilus *Mojsisovics.*								
,, costatus *Hind* . .							×	194.
Stroboceras *Hyatt.*								
,, sulcatum (*J. de C. Sow.*) [Nautilus *auctt.*] . .	×							3*a*.
Vestinautilus *Ryckholt.*								
,, cariniferus (*J. de C. Sow.*).	×							61E.
Ammonoidea.								
Dimorphoceras *Hyatt.*								
,, gilbertsoni (*Phill.*). .	×							3*a*.
Glyphioceras *Hyatt.*								
,, micronotum (*Phill.*) . .	×							3*a*.
,, subtruncatum *Foord* .	×							3*a*.
,, truncatum (*Phill.*) . .	×							3*a*.
,, sp. (2)	×							3*a*.
PISCES.								
Elasmobranchii.								
Pleuracanthus *Agassiz.*								
,, lævissimus *Ag.* . .							×	200T.
,, elegans *Traq.* . . .			×	×				93T, 98T.
,, gracillimus *Traq.* . .			×					98T.
,, horridulus *Traq.* . .			×	×				93T, 98T.
,, fastigiatus (*Davis*) . .			×	×				93T, 98T.
Diplodus *Agassiz.*								
,, gibbosus *Ag.*							×	94T, 201.
,, parvulus *Traq.* . . .		×	×					93T, 98T, 220.
Cladodus *Agassiz.*								
,, mirabilis *Ag.*		×						233.
,, striatus *Ag.*		×						1T, 233.
Dicentrodus *Traquair.*								
,, bicuspidatus *Traq.* . .				×	×			93T, 98T.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
PISCES—*continued.*								
Janassa *Münster.*								
,, clavata *M'Coy.*		×						159.
,, linguæformis *Atthey.*							×	94T.
,, sp. indet.						×		180.
Petalorhynchus *Newberry & Worthen.*								
,, psittacinus (*M'Coy*)		×						167, 233T.
Petalodus *Owen.*								
,, acuminatus *Agass.*		×						1T, 159.
Asteroptychius *M'Coy.*								
,, ornatus *Agass.*		×						157.
Ctenoptychius *Agassiz.*								
,, apicalis *Agass.*							×	94T.
,, lobatus (*R. Eth., junr.*)		×						1T, 157.
,, serratus (*Agass.*)		×						228T.
,, sp. indet.	×		×					21, 43, 81, 169.
Polyrhizodus *M'Coy.*								
,, magnus *M'Coy.*		×						233.
Callopristodus *Traquair.*								
,, pectinatus (*Ag.*)	×		×	×	×			21, 38, 50, 89T, 93T, 98T, 218.
Pristodus *Davis.*								
,, falcatus *Davis*		×						1T.
Copodus *Davis.*								
,, planus *Davis*		×						152T.
Psammodus *Agassiz.*								
,, rugosus *Agass.*		×						1, 167, 228.
,, sp. indet.		×						166.
Helodus *Agassiz.*								
,, simplex *Agass.*							×	× (Mid. Coal Meas.) 94, 195.
,, sp. indet.		×		×				1*a*, 147.
Pleurodus (*Agassiz*), *Hancock & Atthey.*								
,, attheyi (*Barkas*)						×	×	180, 194.
,, falcatus *Traq.*			×					92T, 97T.
,, rankinei *Han. & Atthey.*						×	×	94T, 180.
,, sp. indet.		×	×				×	1*a*, 13, 97T, 113.
Xystrodus *Morris & Roberts.*								
,, striatus *M'Coy*		×						167, 233, 236.
Cochliodus *Agassiz.*								
,, contortus *Ag.*		×						167, 228, 233.
Pœcilodus *M'Coy.*								
,, jonesi (*M'Coy*)		×						1, 233T.
,, sp. indet.		×						168, 236.
Psephodus *Morris & Roberts.*								
,, magnus *M'Coy*		×						168T.
,, sp. indet.		×						166, 232.
Oracanthus *Agassiz.*								
,, armigerus *Traq.*			×	×				92T, 97T, 147.
Acondylacanthus *St. John & Worthen.*								
,, jenkinsoni (*M'Coy*)		×						233T.
Lepracanthus *Owen.*								
,, colei *Owen.*							×	94T.
Tristychius *Agassiz.*								
,, arcuatus *Ag.*	×		×	×				44, 61T, 87T, 89T, 92T, 93T, 97T, 98T, 182.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
PISCES—*continued.*								
Tristychius minor *Port.*	×	×	×	×				87T, 89T, 92T, 93T, 97T, 98T, 233.
,, sp. indet.	×	×						1*a*, 70.
Euphyacanthus *Traquair.*								
,, semistriatus *Traq.*	×		×	×				87T, 92T, 93T.
Sphenacanthus *Agassiz.*								
,, serrulatus (*Ag.*)	×		×	×				72, 87T, 89T, 93T, 98T.
,, sp. indet.				×	×		×	× (Mid. Coal Meas.) 94, 147, 195, 218.
Gyracanthus *Agassiz.*								
,, rectus *Traq.*	×							87T, 89T.
,, nobilis *Traq.*			×					98T.
,, youngi *Traq.*			×					98T.
,, formosus *Ag.*							×	200T.
Aganacanthus *Traquair.*								
,, striatulus *Traq.*	×		×	×				87T, 93T, 98T.
Cynopodius *Traquair.*								
,, crenulatus *Traq.*	×		×	×				87T, 89T, 93T, 98T.
Euctenius *Traquair.*								
,, elegans *Traq.*			×	×				93T, 98T.
Harpacanthus *Traquair.*								
,, fimbriatus (*Stock*)		×						99T.
,, major *Traq.*			×					92T.
Acanthodes *Agassiz.*								
,, wardi *Egert.*							×	94T.
,, sulcatus *Agass.*	×							30T, 44T.
,, sp. indet.	×			×			×	1*a*, 3*a*, 29, 37, 84, 147, 194.
Acanthodopsis *Hancock & Atthey.*								
,, wardi *Han. & Atthey.*							×	94T, 200T.
Crossopterygii.								
Megalichthys *Agassiz.*								
,, hibberti *Ag.*							×	94T, 200T, 208.
,, laticeps *Traq.*	×							89T.
,, lævis *Traq.*	×							87T.
,, pygmæus *Traq.*							×	94T.
,, sp. indet.	×		×			×	×	× (Mid. Coal Meas.) 1*a*, 71, 180, 181, 182, 186, 195, 201.
Rhizodopsis *Huxley.*					×		×	94T, 103, 200T, 204, 208.
,, sauroides (*Will.*)								
,, sp. indet.		×	×			×	×	100, 177, 180, 181, 182, 183, 186, 187, 211, 220, 221.
Rhizodus *Owen.*								
,, hibberti (*Ag.*)	×	×	×	×				1*a*, 7, 30T, 84, 89, 93T, 97T, 98T, 101T.
,, ornatus *Traq.*	×	×		×				84, 87T, 89, 93T, 101T.
Strepsodus *Young.*				?			×	94T, 147.
,, sauroides (*Binney*)							×	94T, 200T.
,, sulcidens (*Atthey*)								
,, striatulus *Traq.*	×		×	×				87T, 93T, 98T.
Cœlacanthus *Agassiz.*							×	× (Mid. Coal Meas.) 94T, 103, 195, 199*a*, 200T, 208.
,, elegans *Newb.*								

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
PISCES—*continued.*								
Cœlacanthus abdenensis *Traq.*			×					92T, 97T.
,, sp. indet.							×	103, 201.
Dipnoi.								
Uronemus *Agassiz.*								
,, lobatus *Ag.*	×							89T.
,, splendens *Traq.*			×					98T.
Ctenodus *Agassiz.*								
,, interruptus *Barkas.*	×		×	×				80T, 87T, 93T, 97T, 98T.
,, cristatus *Ag.*							×	200T ?.
Sagenodus *Owen.*								
,, quinquecostatus *Traq.*		×	×	×				93T, 98T, 101T.
Acipenseroidei.								
Eurylepis *Newberry.*								
,, scoticus *Traq.*			×					98T.
Gonatodus *Traq.*								
,, punctatus (*Ag.*)	×							30T.
,, macrolepis *Traq.*	×	×						87T, 101T.
,, parvidens *Traq.*			×	×				93T, 98T.
Drydenius *Traquair.*								
,, insignis *Traq.*			×					98T.
Elonichthys *Giebel.*								
,, robisoni (*Hibbert*)	×	×	×		?			3*a*, 30, 61T, 80, 84, 87T, 89T, 97T, 98T, 101T, 179 ?.
,, striatus (*Ag.*)	×							30, 87T, 89T.
,, pectinatus *Traq.*	×	×	×	×				1*a*, 3, 87T, 93T, 98T, 147.
,, multistriatus *Traq.*		×						101T.
,, aitkeni *Traq.*							×	94T, 194.
,, sp. indet.	×		×					19, 182, 183, 220.
Mesopoma *Traquair.*								
,, macrocephalum *Traq.*	×							80.
Platysomus *Agassiz.*								
,, parvulus *Agass.*							×	94T.
,, fosteri *Han. & Atthey.*							×	94T.
Acrolepis *Agassiz.*								
,, semigranulosa *Traq.*	×							87T.
Rhadinichthys *Traquair.*								
,, ornatissimus (*Ag.*)	×		×					30, 38, 41, 50, 51, 69, 84, 87T, 89T, 98T.
,, carinatus (*Ag.*)	×		×					30T, 42, 50T, 80, 87T, 89T, 98T, 219, 220.
,, brevis *Traq.*	×							30T.
,, ferox *Traq.*	×							30T.
,, monensis (*Egerton*)						×		180.
Nematoptychius *Traquair.*								
,, greenocki (*Ag.*)	×	×	×	×				30T, 87T, 89T, 93T, 97T, 98T, 101T.
Cryphiolepis *Traquair.*								
,, striatus *Traq.*			×					98T.

GENERA AND SPECIES.	Calciferous Sandstone.	Lower Limestones.	Edge Coals.	Upper Limestones.	Lower third Roslin Sandstone.	Upper two-thirds Roslin Sandstone.	Lower Coal Measures.	Locality Numbers.
PISCES—*continued.*								
Eurynotus *Agassiz.*								
,, crenatus *Ag.* . . .	×	×	×	×				26, 27T, 30, 50, 53T, 61, 64, 80T, 84, 87T, 89T, 92T, 93T, 97T, 101T.
,, microlepidotus *Traq.* . .			×					98T.
,, sp. indet.	×		×					38, 79, 181, 183.
Wardichthys *Traquair.*								
,, cyclosoma *Traq.* . .	×							30T.
Cheirodus *M'Coy.*								
,, granulosus (*Young*) . .							×	94T.
,, crassus *Traq.* . . .			×					92T.
AMPHIBIA.								
Stegocephalia.								
Loxomma *Huxley.*								
,, allmani *Huxley* . . .		×						101H.
Macromerium *Fritsch.*								
,, scoticum *Lydekker* . .		×						101L.
Pholidogaster *Huxley.*								
,, piscidiformis *Hux.* . .		×						101H.

C. LISTS OF POST-TERTIARY FOSSILS (Revised by Dr. Lee).

From C. Reid, "Origin of the British Flora," 1899, p. 72.

HAILES QUARRY, near Edinburgh.

"Two plant-bearing deposits are found at this spot. The lower one rests immediately on the Boulder Clay and yields Arctic plants in the hollows between the boulders."

Lower Bed, Late Glacial.

Thalictrum minus (?) *Linn.*
Ranunculus aquatilis *Linn.*
,, repens *Linn.*
Viola palustris *Linn.*
Lychnis diurna *Sibth.*
Stellaria media *Cyr.*
Oxalis Acetosella *Linn.*
Hippuris vulgaris *Linn.*
Taraxacum officinale *Web.*
Andromeda polifolia *Linn.*
Menyanthes trifoliata *Linn.*
Stachys palustris *Linn.*
Ajuga reptans *Linn.*
Polygonum aviculare *Linn.*
Alnus glutinosa *Linn.*
Salix herbacea *Linn.*
,, polaris *Wahlb.*
,, reticulata *Linn.*
Empetrum nigrum *Linn.*
Eleocharis palustris *Br.*
Scirpus pauciflorus *Lightf.*
Isoetes lacustris *Linn.*

The remains of *Apus* (*Lepidurus*) *glacialis* were also found in this deposit by J. Bennie.

Upper Beds, Neolithic.

Ranunculus aquatilis *Linn.*
,, Flammula *Linn.*
,, Lingua (?) *Linn.*
,, repens *Linn.*
Caltha palustris *Linn.*
Viola palustris *Linn.*
Lychnis diurna *Sibth.*
,, Flos-cuculi *Linn.*
Stellaria media *Cyr.*
,, uliginosa *Murr.*
Montia fontana *Linn.*
Linum.
Oxalis Acetosella *Linn.*
Prunus spinosa *Linn.*
,, Padus *Linn.*
Spiræa Ulmaria *Linn.*
Rubus Idæus *Linn.*
,, fruticosus *Linn.*
Potentilla Tormentilla (?) *Linn.*
,, Comarum *Nestl.*
Cratægus Oxyacantha *Linn.*
Hippurus vulgaris *Linn.*
Æthusa Cynapium *Linn.*
Sambucus nigra *Linn.*
Valeriana officinalis *Linn.*
Chrysanthemum segetum *Linn.*
Matricaria inodora *Linn.*
Cnicus palustris *Willd.*
Lapsana communis *Linn.*
Menyanthes trifoliata *Linn.*
Pedicularis palustris *Linn.*
Lycopus europæus *Linn.*
Stachys palustris *Linn.*
Galeopsis Tetrahit *Linn.*
Ajuga reptans *Linn.*
Atriplex patula *Linn.*
Polygonum Persicaria *Linn.*
Rumex crispus *Linn.*
Mercurialis perennis *Linn.*
Betula alba *Linn.*
Alnus glutinosa *Linn.*
Corylus Avellana *Linn.*
Quercus Robur *Linn.*
Pinus sylvestris *Linn.*
Potamogeton heterophyllus *Schreb.*
,, perfoliatus *Linn.*
,, pusillus *Linn.*
Eleocharis palustris *R. Brown.*
Scirpus pauciflorus *Lightf.*
,, setaceus *Linn.*
,, lacustris *Linn.*
Carex dioica *Linn.*
,, echinata *Murr.*
,, canescens *Linn.*
,, flava *Linn.*
Isoetes lacustris *Linn.*
Chara.
Raphanus Raphanistrum *Linn.**

* Not identified when book was written.

From J. Bennie and T. Scott, "The Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 145).

Candona candida (*Müller*).
Ilyocypris gibba (*Ramdohr*).
Cytheridea torosa *var.* teres (*Jones*).
Pisidium fontinale (*Drap.*).
Planorbis glaber *Jeffr.*
Limnea peregra (*Müller*).
Vertigo pygmæa (*Drap.*).

From J. Simpson and D. Hepburn, "On Mammalian Bones found during Excavations at Hailes Quarry near Edinburgh" (*Trans. Edin. Geol. Soc.*, 1899, vol. viii. p. 27).

Bos primigenius *Boj.*
,, sp.
Equus sp.
Cervus elaphus *Linn.*
Arvicola agrestis *Linn.* (Field Vole).

From C. Reid, "Origin of the British Flora," 1899, p. 86.

REDHALL QUARRY, near Slateford, Edinburgh.

Neolithic.

Ranunculus aquatilis *Linn.*
,, Flammula *Linn.*
,, Lingua *Linn.*
,, repens *Linn.*
Caltha palustris *Linn.*
Fumaria officinalis *Linn.*
Viola palustris *Linn.*
Lychnis diurna *Sibth.*
,, Flos-cuculi *Linn.*
Stellaria media *Cyr.*
,, uliginosa *Linn.*
Spergula arvensis *Linn.*
Montia fontana *Linn.*
Hypericum quadrangulum *Linn.*
,, elodes *Linn.*
Linum.
Oxalis Acetosella *Linn.*
Prunus lusitanica *Linn.*
Spiræa Ulmaria *Linn.*
Rubus Idæus *Linn.*
,, fruticosus *Linn.*
Potentilla Tormentilla *Neck.*
,, Comarum *Nestl.*
Alchemilla arvensis *Lam.*
Rosa canina (?) *Linn.*
Cratægus Oxyacantha *Linn.*
Sambucus nigra *Linn.*
Valeriana officinalis *Linn.*
Eupatorium canabiunum *Linn.*
Bidens cernua *Linn.*
Chrysanthemum segetum *Linn.*
Matricaria inodora *Linn.*
Tussilago Farfara *Linn.*
Senecio sylvaticus *Linn.*
Cnicus lanceolatus *Willd.*
,, palustris *Willd.*
Centaurea Cyanus *Linn.*
Lapsana communis *Linn.*
Crepis virens *Linn.*
Leontodon autumnalis *Linn.*
Taraxacum officinale *Web.*
Sonchus arvensis *Linn.*
Menyanthes trifoliata *Linn.*
Pedicularis palustris *Linn.*
Lycopus europæus *Linn.*
Prunella vulgaris *Linn.*
Stachys palustris *Linn.*
Galeopsis Tetrahit *Linn.*
Ajuga reptans *Linn.*
Littorella lacustris *Linn.*
Atriplex patula *Linn.*
Polygonum aviculare *Linn.*
,, Persicaria *Linn.*
Rumex obtusifolius *Linn.*
,, crispus *Linn.*
Euphorbia Helioscopia *Linn.*
Alnus glutinosa *Linn.*
Quercus Robur *Linn.*
Pinus.
Juncus.
Sparganium ramosum ? *Curtis.*
Alisma Plantago *Linn.*
Potamogeton perfoliatus *Linn*
,, pusillus *Linn.*
Eleocharis palustris *Br.*
Scirpus pauciflorus *Lightf.*
,, setaceus *Linn.*
Carex dioica *Linn.*
,, echinata *Murr.*
,, canescens *Linn.*
,, panicea *Linn.*
,, flava *Linn.*
Agrostis.

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 146).

REDHALL QUARRY.

Deflugia sp.
Cypria opthalmica (*Jurine*).
,, serena (*Koch*).
Cypris incongruens, *Ramdohr.*
Herpetocypris olivacea (?), *B. & N.*
Candona rostrata (*B. & N.*).
,, candida (*Müller*).
Limnicythere inopinata (*Baird*).
Pisidium pusillum (?) (*Gmel.*).

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 154).

REDHALL QUARRY.

Diatoms from Peat Bed in Boulder Clay.

Amphora ovalis *Ktz.*
Ceratoneis arcus *Ktz.*
,, ,, *var.* majus.
Cymbella lanceolata *Ehb.*
,, cistula *Hemper.*
,, gastroides *Ktz.*
,, ,, *var.* minor.
Stauroneis phænicenteron *Nitz.*
,, acuta *W. Sm.*
,, gracilis *W. Sm.*
,, anceps *Ehb.*
Navicula major *Ktz.*
,, nobilis *Ktz.*
,, viridis *Ktz.*
,, gibba *Ktz.*
,, limosa *Ktz.*
,, ovalis *Sm.*
,, anglica *Ralp.*
,, radiosa *Ktz.*
,, cuspidata *Ktz.*
Navicula rhynchocephala *Ktz.*
,, sp.
Pleurosigma attenuatum *W. Sm.*
Gomphonema insigne *Grev.* forma major.
Epithemia gibba *Ehr.*
,, ,, *var.* ventricosa.
Asterionella formosa *Hassal.*
Synedra pulchella *Ktz.*
,, danica *Ktz.*
Tabellaria fenestrata *Lyngb.*
Cymatopleura solea *Sm.*
,, elliptica *Breb.*
Surirella elegans *Ehr.*
,, spiralis *Ktz.*
,, biseriata *Breb.*
Campylodiscus costatus *W. Sm.*
Nitzschia angustata *Grun.*
Hantzia amphioxis *var.* intermedia *Grun.*
Cyclotella comta *Ktz.*

From C. Reid, "Origin of the British Flora," 1899, p. 62.

CORSTORPHINE, Lake Deposits—Arctic Plant Bed—Late Glacial.

Ranunculus aquatilis *Linn.*
,, repens *Linn.*
Viola palustris *Linn.*
Stellaria media *Cyr.*
Rubus.
Dryas octopetala *Linn.*
Potentilla.
Hippuris vulgaris *Linn.*
Myriophyllum spicatum *Linn.*
Taraxacum officinale *Web.*
Andromeda Polifolia *Linn.*
Loiseleuria procumbens *Desv.*
Menyanthes trifoliata *Linn.*
Oxyria digyna *Hill.*
Betula nana *Linn.*
Salix repens *Linn.*
,, herbacea *Linn.*
,, polaris *Wahlb.*
,, reticulata *Linn.*
Empetrum nigrum *Linn.*
Potamogeton.
Eleocharis palustris *Br.*
Scirpus pauciflorus *Lightf.*
,, lacustris *Linn.*
Carex, 2 sp.

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1899, vol. x. p. 143).

CORSTORPHINE, Old Lake Deposit.

Cypria lævis *Müller.*
Cypris incongruens *Ramdohr.*
Herpetocypris reptans (*Baird*).
Ilyocypris gibba (*Ramdohr*).
Candona candida (*Müller*).
,, pubescens (*Koch*).
Cypridopsis aculeata (*Lilljeborg*).
,, vidua (*Müller*).
Cypridopsis villosa (*Jurine*).
Lymnicythere inopinata (*Baird*).
Pisidium fontinale (*Drap.*).
,, nitidum *Jenyns.*
Planorbis glaber *Jeffr.*
,, nautileus (*Linn.*).
Limnæa peregra (*Müller*).
,, truncatula (*Müller*).

From C. Reid, "Origin of the British Flora," 1899, p. 60.

BROUGHTON, Edinburgh City.

Neolithic.

Ranunculus aquatilis *Linn.*
,, Flammula *Linn.*
,, Lingua *Linn.*
,, repens *Linn.*
Stellaria media *Cyr.*
Montia fontana *Linn.*
Carduus.
Atriplex (?)
Polygonum aviculare *Linn.*
,, Persicaria *Linn.*
Rumex.
Potamogeton.
Scirpus setaceus *Linn.*
Eriophorum.
Carex.

From C. Reid, "Origin of the British Flora," 1899, p. 70.

GAYFIELD, Edinburgh City.

Ranunculus aquatilis *Linn.*
,, repens *Linn.*
Viola palustris *Linn.*
Prunus Avium *Linn.*
Rubus Idæus *Linn.*
Cratægus Oxyacantha *Linn.*
Myriophyllum.
Carduus.
Sonchus arvensis *Linn.*
Menyanthes trifoliata *Linn.*
Atriplex (?)
Polygonum Persicaria *Linn.*
Salix polaris *Wahlb.*
,, herbacea *Linn.*
,, reticulata *Linn.*
Potamogeton crispus *Linn.*
,, sp.
Carex.
Phragmites.
Isoetes.

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 143).

HOLYROOD PARK, Old Lake Deposit, near Holyrood Palace.

Cypria lævis *Müller.*
,, serena *Koch.*
Cypris incongruens *Ramdohr.*
Herpetocypris reptans (*Baird*).
Cypridopsis villosa (*Jurine*).
Potamocypris fulva *Brady.*
Candona candida (*Müller*).
,, lactea *Baird.*
,, pubescens (*Koch*).
Ilyocypris gibba (*Ramdohr*).
Limnicythere sancti-patricii (*B. & R.*).
Cytheridea lacustris (*Sars.*).
Limnæa peregra (*Müller*).
Planorbis glaber *Jeffr.*
Valvata piscinalis (*Müller*).
Pisidium pusillum (*Gmel.*).
,, fontinale (*Drap.*).

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 139).

EDINBURGH CITY, Old Lake Deposit in Princes Street Gardens (The "Nor Loch").

Cypria opthalmica (*Jurine*).
Cypris prasina *Fischer.*
Herpetocypris reptans (*Baird*).
Candona candida (*Müller*).
Candona lactea *Baird.*
Limnicythere inopinata (*Baird*).
Pisidium pusillum (*Gmel.*).
Limnæa peregra (*Müll.*).

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 140).

NORTH SIDE OF BLACKFORD HILL, Lacustrine Deposit.

Cypria opthalmica (*Jurine*).
,, serena (*Koch*).
Cypridopsis vidua (*Müller*).
Potamocypris fulva *Brady.*
Candona candida (*Müller*).
,, lactea *Baird.*
,, pubescens (*Koch*).
,, fabæformis (*Fischer*).
Ilyocypris gibba (*Ramdohr*).
Limnicythere inopinata (*Baird*).
Pisidium fontinale (*Drap.*).
,, pusillum (*Gmel.*).
Sphærium corneum (*Linn.*).
Planorbis glaber *Jeffr.*
Limnæa peregra (*Müller*).

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 140).

JORDANVALE LAKE, Morningside, Edinburgh.

Cypria serena (*Koch*).
Cypris incongruens *Ramdohr.*
Herpetocypris reptans (*Baird*).
Cypridopsis vidua (*Müller*).
Potamocypris fulva *Brady.*
Candona candida (*Müller*).
,, fabæformis (*Fischer*).
Limnicythere inopinata (*Baird*).
Sphærium corneum (*Linn.*).
Pisidium nitidum *Jenyns.*
,, pusillum (*Gmel.*).
Planorbis glaber *Jeffr.*
,, nautileus (*Linn.*).
Limnæa peregra (*Müller*).
Physa fontinalis (*Linn.*).

From J. Bennie and T. Scott, "Ancient Lakes of Edinburgh" (*Proc. Roy. Phys. Soc. Edin.*, 1889, vol. x. p. 141).

THE MEADOWS.

Cypria serena (*Koch*).
Herpetocypris reptans (*Baird*).
Candona candida (*Müller*).
,, lactea *Baird*.
Darwinula stevensoni *B. & R.*
Pisidium nitidum *Jenyns*.
Pisidium pusillum (*Gmel.*).
Planorbis nautileus (*Linn.*).
Valvata cristata *Müller*.
,, piscinalis (*Müller*).
Limnæa peregra (*Müller*).

From C. Reid, "Origin of the British Flora," 1899, p. 69.

FILLYSIDE, between Leith and Portobello.

Ranunculus Flammula *Linn.*
,, repens *Linn.*
Viola.
Lychnis diurna (?) *Linn.*
Stellaria media *Cyr.*
Montia fontana *Linn.*
Rubus Idæus *Linn.*
Sambucus nigra *Linn.*
Taraxacum officinale *Web.*
Stachys palustris *Linn.*
Ajuga reptans *Linn.*
Atriplex patula *Linn.*
Rumex.
Mercurialis perennis *Linn.*
Alnus glutinosa *Linn.*
Carex.

From J. Bennie and T. Scott, "The Raised Sea-Bottom of Fillyside" (*Proc. Roy. Phys. Soc. Edin.*, 1892, vol. xi. p. 215).

Anomia ephippium *Linn.*
Pecten opercularis (*Linn.*).
Mytilus edulis *Linn.*
Modiolaria marmorata (*Forbes*).
Nucula nitida *G. B. Sowerby*.
Leda pygmæa (*Münster*).
,, minuta (*Müller*).
Lepton nitidum *Turton*.
Montacuta bidentata (*Montagu*).
Ostrea edulis *Linn.*
Cyamium minutum (*Fabricius*).
Cardium fasciatum *Montagu*.
,, nodosum *Turton*.
Venus lincta *Pultney*.
,, fasciata (*Da Costa*).
Tapes pullastra (*Montagu*).
Tellina tenuis *Da Costa*.
,, fabula *Gronovius*.
Mactra solida *Linn.*
,, subtruncata (*Da Costa*).
Scrobicularia alba (*Wood*).
Mya arenaria *Linn.*
Saxicava rugosa (*Linn.*).
Chiton sp.
Patella vulgata *Linn.*
Helcion pellucidum (*Linn.*).
Tectura virginea (*Müller*).
Trochus cinerarius *Linn.*
,, umbilicatus (*Montagu*).
Lacuna divaricata (*Fabricius*).
,, puteolus (*Turton*).
Lacuna pallidula (*Da Costa*).
Littorina obtusata (*Linn.*).
Littorina rudis (*Maton*).
Rissoa costata (*Adams*).
,, parva (*Da Costa*).
,, membranacea (*Adams*).
,, violacea *Desmarets*.
,, striata (*Adams*).
,, semistriata (*Montagu*).
Hydrobia ulvæ (*Pennant*).
Skenea planorbis (*Fabricius*).
Odostomia unidentata (*Montagu*).
,, spiralis (*Montagu*).
,, scalaris (*Philippi*).
Natica alderi *Forbes*.
Adeorbis subcarinatus (*Montagu*).
Purpura lapillus (*Linn.*).
Murex erinaceus *Linn.*
Nassa reticulata (*Linn.*).
,, incrassata (*Ström.*).
Pleurotoma nebula (*Montagu*).
,, septangularis (*Montagu*).
Utriculus truncatulus (*Bruguière*).
,, hyalinus (*Turton*).
Philine nitida *Jeffreys*.
,, aperta (*Linn.*).

Westbank Brick and Tile Works, near Portobello, from piece of clayey sand embedded in fine brick clay. From Survey List Books. Determinations by H. B. Brady.

Cassidulina lævigata *d'Orb.*
Cristellaria rotulata (*Lamk.*).
Dentalina communis *d'Orb.*
Glandulina lævigata *d'Orb.*
Lagena globosa ? (*Montag.*).
,, lævis (*Montag.*).
Lagena marginata (*W. & B.*).
,, melo (*d'Orb.*).
,, squamosa (*Montag.*).
,, sulcata (*W. & J.*).
Miliolina seminulum (*Linn.*).
Nodosaria humilis *Rœmer*.

WESTBANK—*continued.*

Nodosaria sp.
Nonionina asterisans (*F. & M.*).
Nonionina depressula (*W. & J.*).
Polymorphina lactea (*W. & J.*).
Polystomella arctica *P. & J.*
,, crispa (*Linn.*).
,, striatopunctata (*F. & M.*).
Pulvinulina karsteni (*Rss.*).
Sphæroidina bulloides *d'Orb.*
Truncatulina lobatula (*W. & J.*).
Cythere concinna *Jones.*
,, leioderma *Norman.*
,, mirabilis *Brady.*
,, tuberculata *Sars.*
Cytheridea papillosa *Bosq.*
,, sorbyana *Jones.*

Note by J. Bennie.—This piece of muddy sand was of a greenish hue and was quite speckled with the chalk grit and shelly debris in it. In digging it out, which I could only do in small pieces, I was very careful not to take any of the ordinary clay with it, and I think it was wholly free from such admixture. This piece of shelly mud had every appearance of having been carried in and deposited in the clay when in course of formation, probably from some far-off shore.

25-ft. Raised Beach, drain cutting in, Carolinc Park, Granton. From Survey List Books.

Balanus.
Cardium edule *Linn.*
Lutraria elliptica *Lamk.*
Mactra solida *Linn.*
,, subtruncata (*Da Costa*).
Ostrea edulis *Linn.*
Pecten.
Saxicava ?
Solen siliqua *Linn.*
Tapes ?
Venus gallina ? *Linn.*
Buccinum undatum *Linn.*
Littorina littorea (*Linn.*).
,, obtusata (*Linn.*).
Nassa.
Patella vulgata *Linn.*
Pleurotoma ?
Trochus cinerarius *Linn.*
Turritella terebra (*Linn.*).

Raised Beach, under Prestongrange House, west of Prestonpans. From Survey List Books.

Cardium edule *Linn.*
,, tuberculatum ? *Linn.*
Cyprina islandica (*Linn.*).
Lutraria elliptica *Lamk.*
Mactra solida *Linn.*
,, subtruncata (*Da Costa*).
Mytilus edulis *Linn.*
Ostrea edulis *Linn.*
Pecten maximus (*Linn.*).
,, opercularis (*Linn.*).
Saxicava.
Solen.
Venus gallina *Linn.*
Aporrhais pes-pelicani (*Linn.*).
Buccinum undatum *Linn.*
Dentalium entalis *Linn.*
Helcion pellucidum ? (*Linn.*).
Littorina littorea (*Linn.*).
,, obtusata (*Linn.*).
Nassa.
Purpura lapillus (*Linn.*).
Trochus cinerarius *Linn.*
Turitella terebra (*Linn.*).
Helix nemoralis *Linn.*

25-ft. Raised Beach, pit at tilework, Morrison's Haven, Prestongrange, west of Prestonpans.

Mactra subtruncata (*Da Costa*).
Ostrea edulis *Linn.*
Tapes pullastra (*Montagu*).
Littorina littorea (*Linn.*).
Littorina obtusata (*Linn.*).
Patella vulgata *Linn.*
Purpura lapillus (*Linn.*).

POST-TERTIARY MAMMALIA.

Compiled from W. Evans, "The Mammalian Fauna of the Edinburgh District," 8vo, Edin., 1892; "The Catalogue of the Museum of the Society of Antiquaries of Scotland." Sir W. Turner, "On the Species of Seal found in Scotland in Beds of Glacial Clay," in *Journ. Anatomy and Physiology*, 1870, vol. iv. p. 260; and A. S. Woodward and C. D. Sherborn, "A Catalogue of British Fossil Vertebrata." Lond., 1890.

Alces machlis *Ogilby* ("Elk") Duddingston Loch, Holyrood Park.
,, ,, ,, (,,) Greycrook, near Cramond.
Cervus elaphus *Linn.* (Red Deer) Greencraig, near Dreghorn, Pentland Hills.
,, ,, ,, (,,) Hailes Quarry, near Slateford.

Post-Tertiary Mammalia—*continued.*

Cervus elaphus *Linn.* (Red Deer) Haugh Burn, between Cauldhame and Parkly Craigs, 1½ miles S.E. of Linlithgow.
,, ,, ,, (,,) Craigcrook Farm, near Edinburgh.
,, ,, ,, (,,) The Meadows, Edinburgh City.
,, ,, ,, (,,) Holyrood ,, ,,
,, ,, ,, (,,) Joppa.
Rangifer tarandus (*Linn.*) (Reindeer) Greencraig, near Dreghorn, Pentland Hills.
,, ,, ,, (,,) Craigton, 1 mile E. of Philipstoun.
,, ,, ,, (,,) Loch at Dundas Castle, near Dalmeny.
Bos taurus *Linn. var.* longifrons *Owen.* Kinleith.
,, ,, ,, ,, ,, ,, Nor Loch, Edinburgh City.
,, ,, ,, ,, ,, ,, Inveresk.
,, ,, ,, ,, ,, ,, Island of Inchkeith.
,, ,, ,, ,, primigenius *Boj.* (Great Extinct Ox) Hailes Quarry, near Slateford.
,, ,, ,, ,, ,, ,, Loch at Dundas Castle, near Dalmeny.
Equus sp. (Horse) Hailes Quarry, near Slateford.
,, ,, ,, Greencraig, near Dreghorn, Pentland Hills.
Elephas primigenius *Blum.* (Mammoth) Clifton Hall, 9 miles W. of Edinburgh.
Microtus agrestis (*Linn.*) (Field Vole) Hailes Quarry, near Slateford.
Canis lupus *Linn.* (Wolf) Greencraig, near Dreghorn, Pentland Hills.
Phoca hispida *Schreber* (Seal = Floe rat of sailors) Portobello brick clay.

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EXPLANATION OF PLATE IX.

FIGS. 1 and 2. *Silicified rhyolite or trachyte*, Camp Hill Quarry, 3 miles west of Penicuik, Pentland Hills. (Fig. 1 is taken by ordinary light, slide No. 9106, and Fig. 2 with crossed nicols; the field is the same, magnified 15 diameters in both cases.) In ordinary light (Fig. 1) the rock resembles a trachyte or rhyolite with steam cavities and two generations of felspar crystals, but in polarised light (Fig. 2) it breaks up into a mosaic of irregular interlocking grains of quartz. This is an example of silicification with very complete preservation of the original rock-structures.

FIG. 3. *Quartz diabase*, quarry on north side of West Bangour, 3½ miles north-east of Bathgate, Linlithgowshire (slide No. 12,130, between crossed nicols, magnified 50 diameters). The large polysynthetic plagioclase felspars are highly zonal and are embedded in abundant micropegmatite.

FIG. 4. *Quartz hypersthene diabase*, North Queensferry, north end of cutting above the tunnel (ordinary light, slide No. 12,184, magnified 14 diameters). To the left and near the centre are crystals of hypersthene weathering to green bastite, etc. There are also black, very irregular crystals of titaniferous iron oxide. The pale green augite shows the pyroxene cleavage; above and to the right is a twinned crystal. The plagioclase felspars sometimes penetrate the augite; in other places the augite is idiomorphic. The microcrystalline mesostasis is filled with secondary products and is hardly distinguishable from the weathered felspars. The structure is partly ophitic, partly intersertal.

FIG. 5. *Quartz diabase*, North Queensferry, south of deep quarry and at higher level than the houses (slide No. 12,187, magnified 18 diameters, ordinary light). This rock is comparatively coarse grained, the ingredients are titaniferous iron oxides, augite and plagioclase felspar. The augite is pale brown and often in its interior is striated parallel to the basal plane; a large crystal with this structure lies near the centre of the field; it has an outer zone free from striation. Of the other crystals of pyroxene some are striated but others are not.

FIG. 6. *Quartz diabase*, fine grained (diabase aphanite), Bog Cottage, one mile south of Linlithgow (slide No. 12,078, magnified 15 diameters, ordinary light). A rounded steam cavity is filled with infiltrated magma, which has crystallized as long needles of a ferromagnesian mineral (decomposed) and feathery felspars. Around the cavity the felspars of the rock are tangentially arranged.

Fig. 1.

Fig. 2.

Fig. 3.

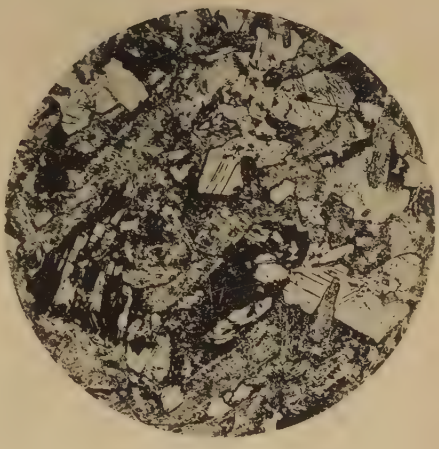

Fig. 4.

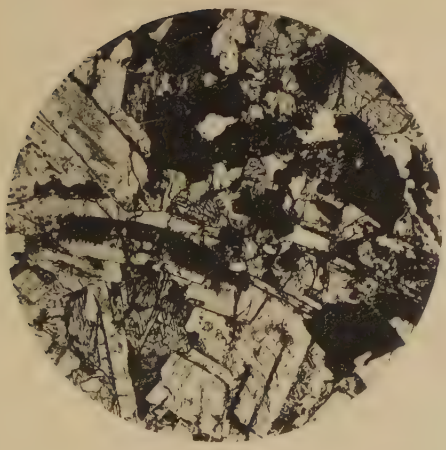

Fig. 5.

Fig. 6.

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EXPLANATION OF PLATE X.

FIG. 1. *Edge of diabase sill* at Hound Point, Dalmeny, in contact with altered shale (slide No. 1215, magnified 30 diameters, ordinary light). The diabase (on the left) is very fine grained with granular cryptocrystalline matrix containing phenocrysts of plagioclase, augite and decomposed olivine. The shale (on the right) shows pseudomorphs which apparently represent pseudo-hexagonal prisms of cordierite.

FIG. 2. Quarry near Ochiltree Mill, Linlithgow (slide No. 11,931, magnified 22 diameters, ordinary light). *Chilled edge of a diabase sill*, porphyritic, with decomposed groundmass of spherulitic tachylyte.

FIG. 3. *Spotted calc-silicate hornfels*, near margin of dolerite-picrite intrusion, Barnton railway cutting, near Edinburgh (slide No. 6046, magnified 17 diameters, ordinary light). The photograph shows large stellate bundles of pale green vesuvianite prisms in a spherulitic matrix of wollastonite and garnet. The garnet is seen at the top of the figure on the left side.

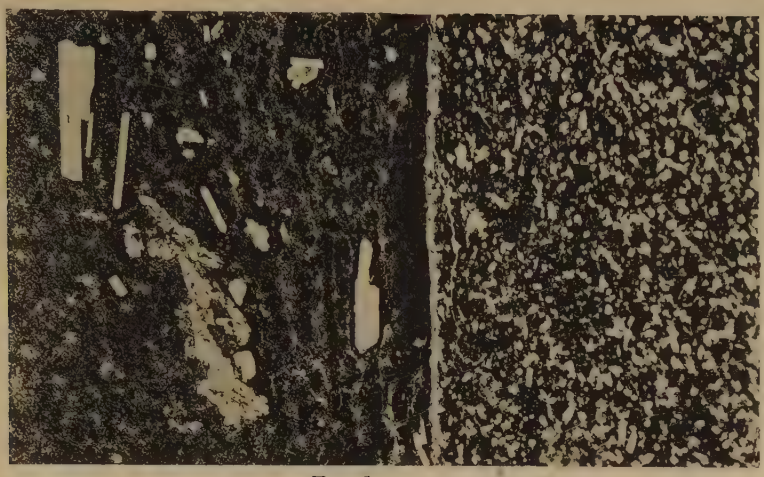

Fig. 1.

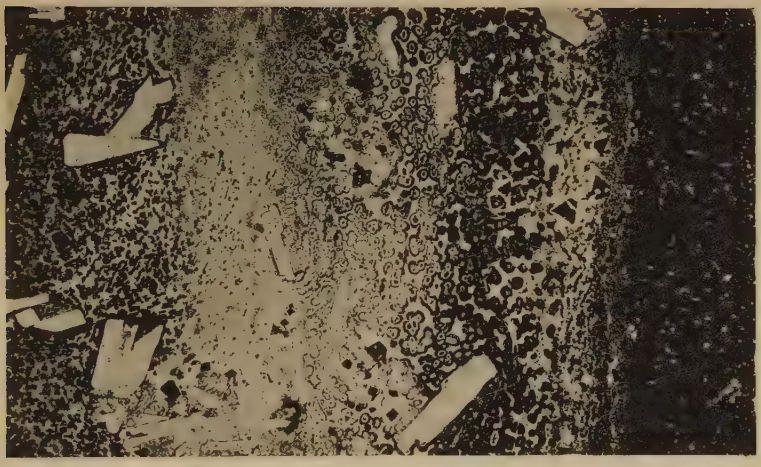

Fig. 2.

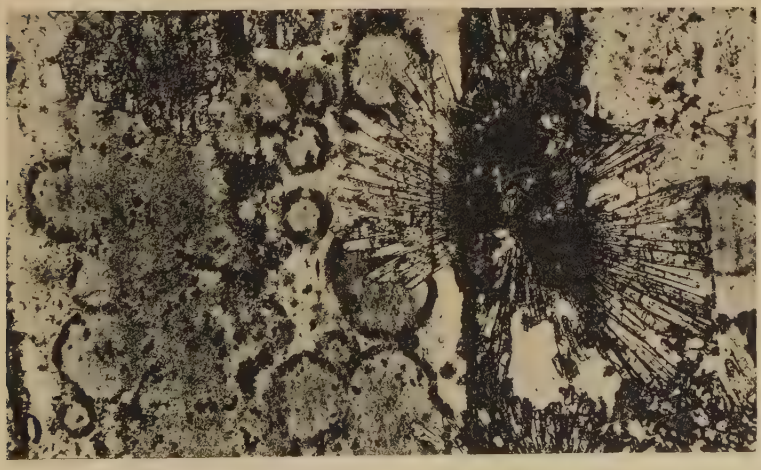

Fig. 3.

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EXPLANATION OF PLATE XI.

FIG. 1. *Teschenite*, quarry on Queensferry Road one mile east-south-east of south end of Forth Bridge (slide No. 12,170, magnified 18 diameters, ordinary light). The rock contains large crystals of augite enclosing portions of elongated plagioclase felspars. The dark patches represent titaniferous magnetite and dark green pseudomorphs after olivine. In the centre there is a patch of clear analcite in which lies a prism of apatite. The felspars are weathered and partly replaced by analcite and zeolites.

FIG. 2. *Picrite*, south side of railway cutting, Barnton, near Edinburgh (slide No. 6041, magnified 26 diameters, ordinary light). The field is occupied mostly by a large crystal of augite which is poikilitic with enclosures of olivine. At the edges of the photograph the olivine is serpentinised.

FIG. 3. *Olivine basalt* (Craiglockhart type), Craiglockhart, near Edinburgh (slide No. 13,571, magnified 10 diameters, ordinary light). Large phenocrysts of decomposed olivine and of augite lie in a finer-grained groundmass of plagioclase, augite and iron oxides.

FIG. 4. *Olivine basalt* (Jedburgh type), Whinny Hill, Arthur's Seat, 100 yards south-east of St. Margaret's Loch (slide No. 11,989, magnified 25 diameters, ordinary light). The micro-ophitic groundmass of a basalt of Jedburgh type. The dark areas are partly magnetite and partly serpentinised olivine.

FIG. 5. *Mugearite*, quarry on the road-side, 1½ miles south-south-east of Kirknewton (slide No. 4916, magnified 30 diameters, ordinary light). The fine-grained fluidal rock consists mainly of small lath-shaped crystals of oligoclase with dark green pseudomorphs after olivine, and small grains of magnetite.

FIG. 6. Vein of *fine porphyritic basalt*, with devitrified groundmass, penetrating the sandstones of Salisbury Crags, Arthur's Seat, at the margin of the teschenite sill (slide No. 1280, magnified 15 diameters, ordinary light). The white porphyritic crystals are plagioclase felspar; the basalt matrix is dark and fine grained.

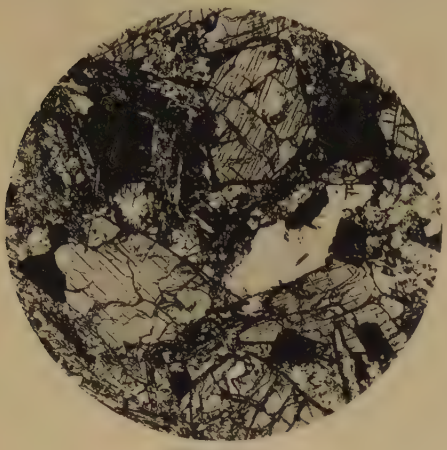


Fig. 1.

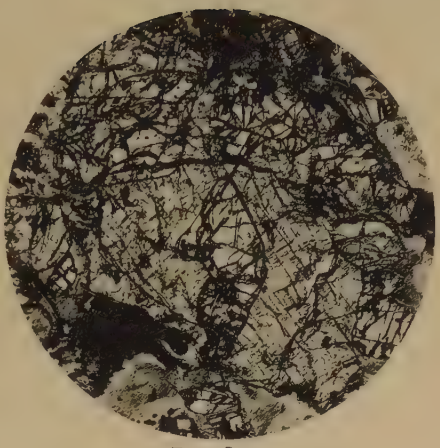


Fig. 2.

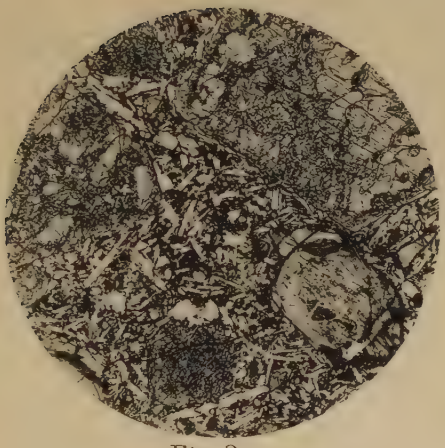


Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Huth coll.

EXPLANATION OF PLATE XII.

FIG. 1. *Olivine basalt*, Lion's Haunch, Arthur's Seat (slide No. 13,572, magnified 10 diameters, ordinary light). Large phenocrysts of plagioclase, augite and olivine; groundmass finely crystalline—Lion's Haunch type.

FIG. 2. *Olivine basalt*, Dunsapie, Arthur's Seat (slide No. 12,013, magnified 15 diameters, ordinary light). Porphyritic plagioclase, augite and olivine; groundmass coarser than in preceding rock, and contains analcite and biotite—Dunsapie type.

FIG. 3. *Olivine basalt*, 300 yards south-south-east of St. Anthony's Chapel, Arthur's Seat (slide No. 11,987, magnified 15 diameters, ordinary light). Porphyritic olivine and augite, but not plagioclase—Craiglockhart type. (See also Plate XI., fig. 3.)

FIG. 4. *Olivine basalt*, railway-cutting at back of engine shed, St. Margaret's Works, near Edinburgh (slide No. 11,994, magnified 10 diameters, ordinary light). Porphyritic plagioclase and olivine, but not augite. The olivine is represented only by pseudomorphs of hematite and limonite—Markle type.

FIG. 5. *Olivine basalt*, small quarry at the powder magazine, Wester Dalmeny Oil Works (slide No. 12,171, magnified 15 diameters, ordinary light). Many small phenocrysts of olivine but few of augite or felspar, groundmass rather rich in felspar—Dalmeny type.

FIG. 6. *Olivine basalt*, Hillhouse quarry, 2 miles south of Linlithgow (slide No. 1670, magnified 10 diameters, ordinary light). With many olivine phenocrysts and few of augite, like the preceding rock; groundmass more rich in augite and with fewer felspars—Hillhouse type.

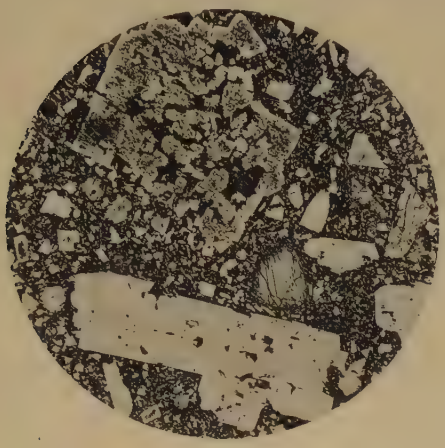
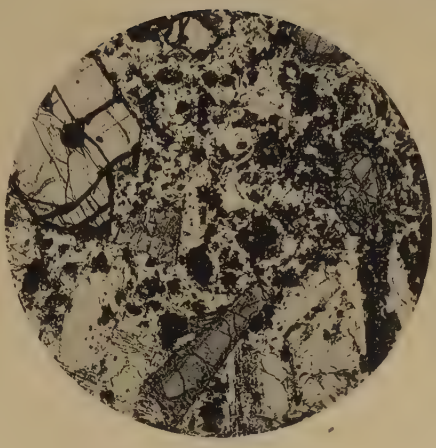


Fig. 1.



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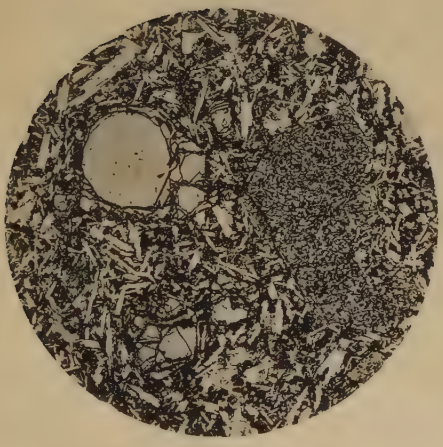


Fig. 3.

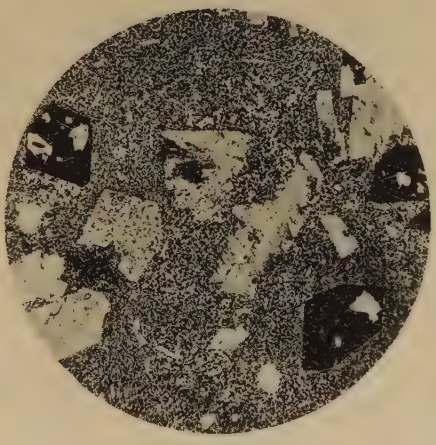


Fig. 4.

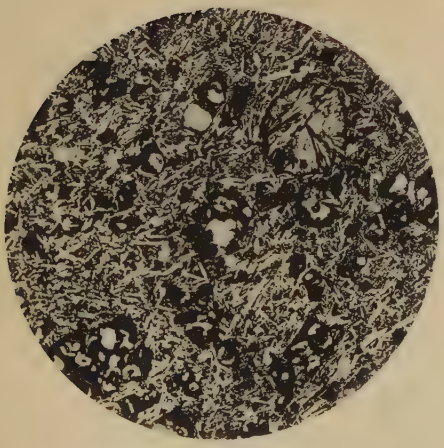


Fig. 5

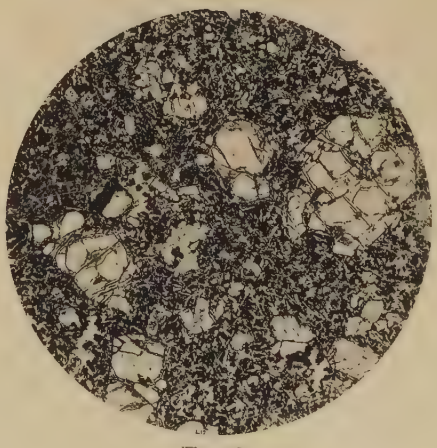
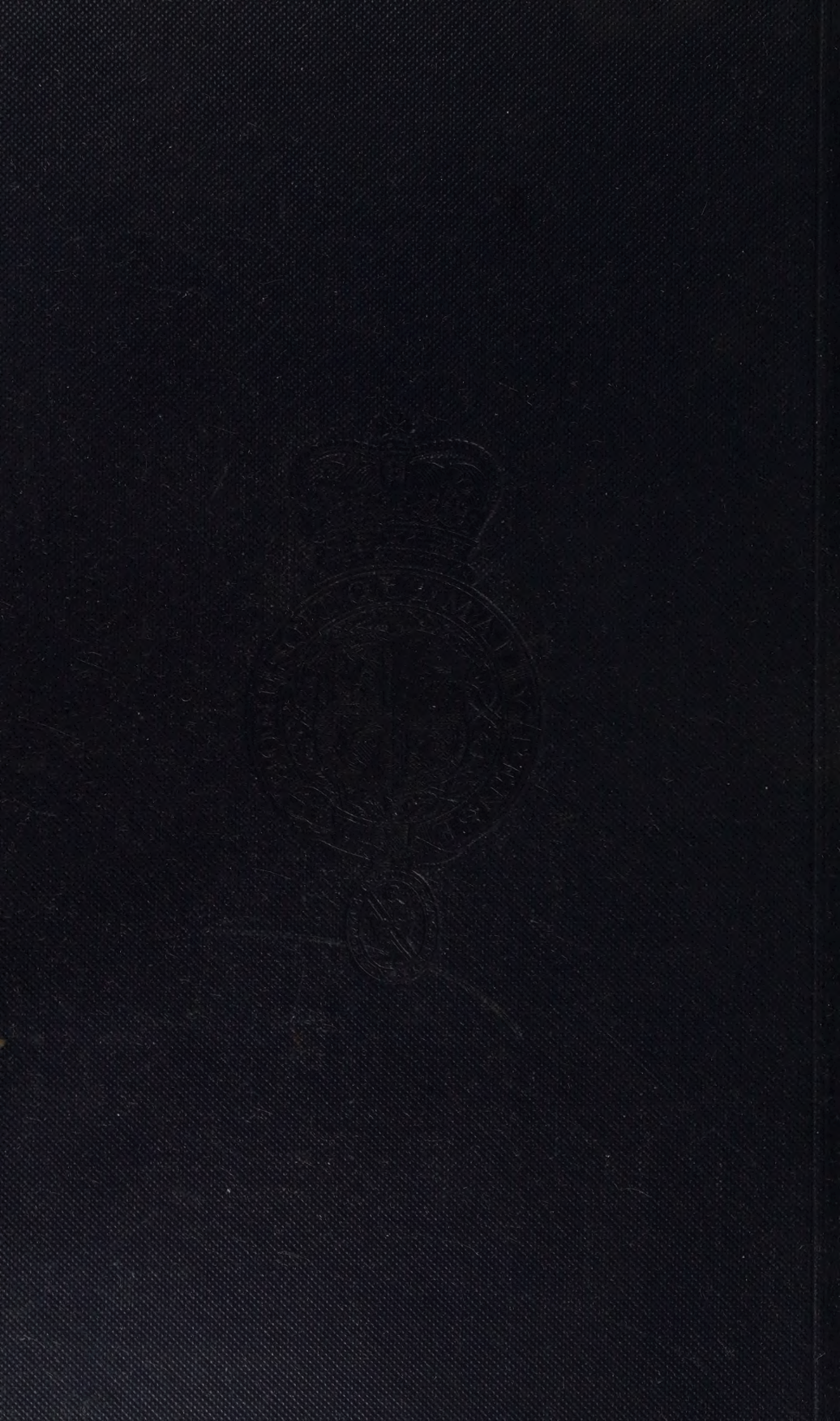


Fig. 6.

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